MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

REPORT OF THE
TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

MAY 2019

VOLUME 4: DECISION XXX/5 TASK FORCE REPORT ON COST AND AVAILABILITY OF LOW-GWP TECHNOLOGIES/EQUIPMENT THAT MAINTAIN/ENHANCE ENERGY EFFICIENCY

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United Nations Environment Programme (UNEP)
Report of the Technology and Economic Assessment Panel

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Volume 4: Decision XXX/3 Task Force Report on Cost and Availability of Low-GWP Technologies/Equipment that Maintain/Enhance Energy Efficiency

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Foreword

The 2019 TEAP Report

The 2019 TEAP Report consists of 4 volumes:

Volume 1: TEAP 2019 Progress report

Volume 2: MBTOC interim CUN assessment report

Volume 3: Decision XXX/3 Task Force Report on Unexpected Emissions of Trichlorofluoromethane (CFC-11)

Volume 4: Decision XXX/5 Task Force Report on Access of Article 5 Parties to Energy-efficient Technologies in the RACHP Sectors

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VOLUME 4: DECISION XXX/5 TASK FORCE REPORT ON COST AND AVAILABILITY OF LOW-GWP TECHNOLOGIES/EQUIPMENT THAT MAINTAIN/ENHANCE ENERGY EFFICIENCY

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Glossary

APF: Annual Performance Factor (see Seasonal Energy Efficiency Ratio). Represents heating and cooling capacity per kilowatt hour (kWh) over one year of use of an air conditioner under specific conditions;

Coefficient of performance (COP, sometimes CP or CoP): For a heat pump, refrigerator or air conditioning system, this is a ratio of useful heating or cooling provided to work required. Higher COPs equate to lower operating costs. It is the ratio of the heating capacity to the effective power input to the device at any given set of rating condition (ISO 5151:2017-7). It is expressed in Watts divided by the power input in Watts (unit-less measure).

Cooling capacity: A measure of a system's ability to remove heat. Measured in kW, BTU/h, or refrigeration ton (RT), where 1 RT = 3.5 kW = 12,000 BTU/h.

Cooling/heating load: The amount of energy needed to heat or cool to a desired level of service. Improving insulation in a building is a strategy for reducing heating and cooling load while providing the same level of comfort to the occupant.

Coefficient of Performance (COP): COP is defined as the ratio between the cooling capacity and the power consumed by the system. COP is also used for heat pumps and in this case it is defined as the ratio between the heating capacity and the power consumed by the system. More specifically, it is the ratio of the total cooling capacity to the effective power input to the device at any given set of rating conditions (ISO 5151:2017-7). This ratio can either be in BTU per hour divided by power input Watts (BTU/h/W), or in Watt/Watt (W/W). The conversion factor is 3.412 BTU/h/W = 1 W/W.

CSPF: Cooling season performance factor (see Seasonal Energy Efficiency Ratio).

Design efficiency: The energy performance of equipment as designed or as shipped, same as nameplate efficiency.

Energy Efficiency Ratio (EER): Ratio of the cooling output divided by the electrical energy input when measured at full load (i.e., at the maximum cooling capacity or the design point) and is measured in W/W or Btu/h/W (1 W = 3.412 Btu/h).

Energy performance: The amount of energy consumed for a piece of equipment or system to perform a specific level of service.

HSPF: Heating Seasonal Performance Factor (see Seasonal Energy Efficiency Ratio)

Installed efficiency: The energy performance of equipment as installed.

ISEER: Indian Seasonal Energy Efficiency Ratio.

Kilowatthour (kWh): A measure of electricity defined as a unit of work or energy, measured as 1 kilowatt (1,000 watts) of power expended for 1 hour. One kWh is equivalent to 3,412 British Thermal Units (Btu).

Manufacturing cost: cost to manufacture the equipment.

Million tonnes oil equivalent (Mtoe): 1 Mtoe = 11.63 billion kWh

Nominal design point: represents the set of conditions (e.g. indoor and outdoor temperatures) used to design the system

Operating cost: The cost to the equipment user to operate the equipment.

Part-load operation: condition that happens when the system has to face a load lower than nominal (nominal conditions are used for the design of the system). RACHP systems usually operate at part-load conditions for most part of their life cycle.

Peak Load: The highest electricity demand occurring within a given period on an electric grid.

Percent energy efficiency improvement: percent change in energy consumption of an efficient unit compared with a base unit.

Refrigeration Ton (RT): Measure of cooling capacity, where 1 ton refers to 12,000 Btu, equivalent to the energy required to freeze 2000 pounds of water in 24 hours.

Retail price: Price to purchase the equipment.

Seasonal Energy Efficiency Ratio (SEER): Ratio of cooling output divided by the electrical energy input, measured at full and part-load, and weighted to represent the overall performance of the device for the weather over a typical cooling season in each given country. An alternative name to SEER is the **Cooling Seasonal Performance Factor (CSPF)**. **Heating Seasonal Performance Factor (HSPF)** is used for heating mode. **Annual Performance Factor (APF)** is a metric used for reversible heat-pump room air conditioners that heat and cool.

Unit energy consumption: The amount of energy consumed by a unit of equipment, usually over one year.

Variable speed drives (VSD): A type of motor controller that drives an electric motor by varying the frequency and voltage supplied to the electric motor, also known as inverter.

Variable refrigerant flow (VRF): AC units that are typically more complex units which generally have a compressor, and condensing unit, but multiple evaporating units in separate conditioned spaces, employing a complex control system. The control system adjusts the refrigerant flow to achieve the desired air-conditioning for each of the different spaces being conditioned.

Executive Summary

The Energy Efficiency Task Force has made an assessment of the availability and costs of technologies and equipment that enhance energy efficiency during HFC phase-down, focusing on air conditioners (AC) and commercial refrigeration (CR). The technology to enhance energy efficiency (EE) using different types of refrigerants is available to varying degrees in the different regions of the world. Research and development (R&D), is ongoing, both for refrigerants and for the new technologies that use these refrigerants in an efficient way. Costs and market incentives are important factors in the availability of energy efficient technologies. Countries which utilize market incentives to drive up the energy efficiency of AC and CR in parallel with HFC phasedown will benefit economically and environmentally. Part of the transition to lower-GWP technologies and equipment has already happened; some markets have been transitioning to higher EE technologies and/or equipment.

CHAPTER 2: AVAILABILITY OF LOW GWP TECHNOLOGY AND EQUIPMENT THAT MAINTAIN OR ENHANCE ENERGY EFFICIENCY

General Considerations

- Medium and low-GWP refrigerants are widely available and do not limit the demand for AC.
- AC and CR equipment meeting the minimum EE requirements in the respective countries are widely available for all refrigerant families including HCFCs; however, extremely limited development to achieve higher EE is taking place on HCFC equipment due to their phase-out schedules.
- Where markets and supporting policies provide clear signals towards alternative refrigerant choice, manufacturers invest in related R&D for those refrigerants while maintaining or enhancing energy efficiency. As a consequence, the R&D effort to develop energy efficient RAC (Refrigeration and Air Conditioning) equipment is being focused on lower GWP technologies. This is particularly visible in the HCFC-22 transition, where no manufacturers supply high-efficiency variable-speed air conditioners using HCFC-22. While the development of new efficient equipment with high GWP HFCs is still taking place in some regions, most effort is now being put into developing energy efficient equipment with medium- and low-GWP refrigerants that exceed the minimum EE ratings by 10% or more.
- Some components to enhance EE in use in AC and CR equipment with lower GWP refrigerants are not widely available[1]. Components for medium-GWP refrigerants are more widely available with some countries transforming the majority of their consumption to these refrigerants.
- Intellectual Property (IP): Most of the widely available new technologies contributing to higher EE equipment are not directly impacted by IP considerations. However, for

[1] This Report defines “availability” in 3 tiers: Low-tier: AC units which meet a regional or country required energy efficiency MEPS; Mid-tier: AC units which are up to 10% more efficient than the base MEPS; and High-tier: AC units which are at least 10% or higher than the base MEPS.

technologies available from a limited number of suppliers, emerging technologies, or R&D technologies, the IP impact has to be determined on a case-by-case basis.

Air Conditioning equipment:

- HCFC-based AC generally has a lower EE, with no on-going R&D to improve EE.
- High GWP refrigerant-based ACs are available around the world across all tiers of EE.
- Medium and lower GWP refrigerant-based AC is “available” in many parts of the world, but in some important markets (e.g. US, HAT countries) it remains an “new technology”.

Air Conditioning components:

The most important factor in developing any new product is the availability of components, such as compressors and heat exchangers.

- Higher efficiency and inverter driven compressors are available and presently used (mostly used for rotary). There is very limited availability for two-stage compression
- China produces 60% of rotary compressors worldwide (200 million/year). Its production of variable speed compressors (inverter) has doubled in 5 years to 70 million/year. This has been driven by the introduction of Minimum Energy Performance Standards (MEPS) in many important markets.
- Heat exchangers are still mainly “fin and tube” type; there is a move to smaller tube diameters and to micro-channel exchangers.
- These higher EE components reduce the refrigerant charge and are valuable in enabling medium and lower GWP flammable refrigerant AC units to comply with safety standards. They are widely available and presently in use.

Commercial Refrigeration equipment:

- Self-Contained Commercial Refrigeration Equipment (SCCRE) units are diverse in design, construction and function. They are made on small to medium scale (100’s to few thousand). They must have high reliability since they often contain perishable foods. The equipment design (vertical vs horizontal, doors) impacts the heat load.
- The refrigerants used in CR were previously limited to HCFC-22, R-404A, and HFC-134a, but this is now changing with CO_2, hydrocarbon units using HFC-600a and HC-290, and with HFO blends (based on HFO-1234yf) being introduced in many countries.

Commercial Refrigeration components:

- The combination of variable speed compressor with modern control technology, cabinet design and inclusion of doors or curtains makes the most significant contribution to improvement of energy efficient SCCRE.
- The majority of technical options for reducing energy consumption listed in this report indicate that they are available today and presently in use.

HAT considerations for Air conditioning and Commercial refrigeration

- Large-scale testing projects of AC prototypes using low- and medium-GWP refrigerants have identified several refrigerants which provide comparable efficiencies in HAT conditions. The MLF-funded PRAHA-II is re-testing optimized units, using

efficient compressors and heat exchangers, which were rebuilt from the original prototypes used in PRAHA-I. The results should be available in late 2019.
- HAT conditions are not generally an issue for commercial refrigerators (SCCRE), which are often placed inside air-conditioned stores and shops. However, in Article 5 parties, SCCRE are sometimes placed outdoors to prevent additional heat load inside the building and this will impact performance due to HAT.

CHAPTER 3: COST OF LOW-GWP TECHNOLOGIES AND EQUIPMENT THAT MAINTAIN OR ENHANCE ENERGY EFFICIENCY IN AC AND CR

- Local industries in A5 parties with AC manufacturing or assembly plants may need financial assistance to convert facilities for safe use of flammable refrigerants, and to in-license technological advances for EE.
- A transition from manufacturing RAC equipment from low to high flammability refrigerants (high to low GWP), requires additional capital and operating costs.
- There are additional capital and operating costs for conversion of manufacturing to flammable refrigerants, and at the same time to incorporate technology for energy efficiency. The Task Force has provided detailed estimates of the additional costs
- Refrigerant cost accounts for ~1% of the overall RAC equipment cost. It is predicted that HFC costs will rise as phasedown progresses and this will make low GWP refrigerants increasingly cost-competitive.
- Compressors account for ~20% of the cost of RAC equipment. Efficiency can be improved by up to 20% by technical advances, but cost increases proportionately.
- Heat exchangers of the "fin and tube" type have improved their efficiency with the introduction of small diameter tubes. Most recently the switch to micro-channel heat exchangers has been accelerating – they have similar or marginally lower cost (~5%) and up to 5% higher efficiency. They reduce the refrigerant charge by ~40%
- Optimising airflow improves EE. The power and cost of fans increase in a stepwise fashion, leading to a complex relationship between increasing cost and EE. The cost effectiveness for optimal EE is determined on a case-by-case basis.
- Other technologies including self-cleaning to reduce dust deposition are a marginal cost.
- At any given time ("snapshot") there is a level of efficiency above where Life Cycle Cost analysis indicates for both AC and CR, that there is a ceiling of efficiency, above which the energy savings will not payback the higher capital cost within the lifetime of the equipment. As the cost for efficient components and designs decrease over time due to increases in scale of production or learning, the cost of higher efficiency equipment decreases. As this occurs, higher levels of efficiency pay back over shorter periods.

CHAPTER 4: ROLE OF MARKETS IN THE TRANSITION TO ENERGY EFFICIENT RAC EQUIPMENT AND LOW GWP REFRIGERANTS

- Price to consumers is only loosely correlated with EE. Enterprise pricing strategies, and especially the inclusion of features that are irrelevant for EE, influence the price to a greater degree.
- EE measures deliver significant positive environmental impacts and reduces the amount of electricity that needs to be generated to deliver the same level of cooling service. National policies (MEPS, labels, pull-policies) have a significant impact on technology/product availability and price. Individual countries setting long-term targets

for energy efficiency alongside the Montreal Protocol/ Kigali Amendment transition, would give their markets a clear trajectory and increase investor confidence that there will be a market for higher-efficiency products

- In addition to focusing on availability or costs, the transition towards energy efficient AC and CR can be accelerated by improving national regulations such as MEPS, market incentivisation, improving servicing capacity and training, as well as promoting financial support for local industry in A5 parties for access to IP and know-how, and capital cost conversion of manufacturing lines.
- Many A5 parties do not have local AC manufacturing and import AC equipment. They may need assistance to develop MEPS and labelling programmes to avoid importing low energy-efficiency AC equipment. For example, of African countries, currently 23 of 54 do not have MEPS. A strategy of early switching towards energy efficient low-GWP AC equipment would bring long-term economic and environmental benefits.
- The transition to lower-GWP and higher efficiency AC equipment can happen together at lower overall cost than otherwise and can be further accelerated by encouraging R&D for new solutions and approaches and through regional and international cooperation and partnerships
- Article 5 parties using HCFC technologies and with low EE or no MEPS regulations have the greatest scope to improve the EE of equipment, compared to countries with high EE MEPS regulations and already using HFCs technologies. They have the opportunity to transition directly to high efficiency/lower GWP equipment while avoiding high-GWP HFCs.
- The adoption of common standards for testing and qualification methods between markets would enable manufacturers to capitalize on scale and accelerate technology readiness. Governments setting testing and performance requirements that are not comparable with main trading partners or suppliers may disadvantage that country economically by delaying the adoption of new energy efficient technologies in that country.
- Awareness influences market and consumer choice. A good consumer communication strategy is critical to increase market penetration of more efficient products.
- International cooperation as well as regional partnerships and the development of similar metrics enable monitoring of the market, which allows an easy comparison of products on the market in different geographic regions.
- The transition can be further accelerated through regional and international cooperation and by encouraging R&D for new solutions and approaches towards low GWP and energy efficient equipment.

1 Introduction

1.1 Decision XXX/5

At their 30th Meeting, parties adopted Decision XXX/5: Access of parties operating under paragraph 1 of Article 5 of the Montreal Protocol to energy-efficient technologies in the refrigeration, air-conditioning and heat-pump sectors. Paragraphs 1-3 of the text of Decision XXX/5 is as follows:

Noting that the Kigali Amendment to the Montreal Protocol will enter into force on 1 January 2019,

Noting also the opportunities cited by the Technology and Economic Assessment Panel in its May 2018 report and the September 2018 revision of that report, where it is noted that several categories of enabling activities can potentially serve to promote energy efficiency,

Acknowledging the Scientific Assessment of Ozone Depletion:2018, which notes that improvements in the energy efficiency of refrigeration and air-conditioning equipment during the transition to low-global-warming-potential alternative refrigerants can potentially double the climate benefits of the Kigali Amendment,

Taking note of paragraphs 16 and 22 of decision XXVIII/2,

1. To request the Executive Committee of the Multilateral Fund to consider flexibility within the financial support provided through enabling activities for HFCs to enable parties operating under paragraph 1 of Article 5 of the Protocol who wish to do so, to use part of that support for energy efficiency policy and training support as it relates to the phase-down of controlled substances, such as:

(a) Developing and enforcing policies and regulations to avoid the market penetration of energy-inefficient refrigeration, air-conditioning and heat-pump equipment;

(b) Promoting access to energy-efficient technologies in those sectors;

(c) Targeted training on certification, safety and standards, awareness-raising and capacity-building aimed at maintaining and enhancing energy efficiency;

2. To request the Executive Committee of the Multilateral Fund to consider, within the context of paragraph 16 of decision XXVIII/2, increasing the funding provided to low-volume consuming countries to assist them in implementing the activities outlined in paragraph 1 of the present decision;

3. To request the Technology and Economic Assessment Panel to prepare a report on the cost and availability of low-global-warming-potential technologies and equipment that maintain or enhance energy efficiency, inter alia, covering various refrigeration, air-conditioning and heat-pump sectors, in particular domestic air-conditioning and commercial refrigeration, taking into account geographical regions, including countries with high-ambient-temperature conditions.

This report presents TEAP’s response to paragraph 3 of the above decision.

1.2 Approach and sources of information

1.2.1 Approach

In order to prepare its report responding to Decision XXX/5, the TEAP established a task force. The composition of the Decision XXX/5 Task Force is as follows:

Co-chairs	Party
* Helene Rochat, Member, RTOC	CH
Roberto Peixoto, Co-chair, RTOC	BRA
Ashley Woodcock, Co-chair, TEAP	UK
Members	
* Omar Abdelaziz, Independent expert	EG
* Gabrielle Dreyfus, Independent expert	US
* Bassam Elassaad, Member, RTOC	LB
Jitendra Bhambure, Independent expert	IN
Suely Carvalho, Senior expert, TEAP	BRA
Daniel Colbourne, Member, RTOC	UK
Samir Hamed, Member, RTOC	JO
Herlianika Herlin, Member, RTOC	ID
Mary Koban, Member, RTOC	US
Holger Koenig, Member, RTOC	DE
Tingxun Li, Member, RTOC	PRC
Bella Maranion, Co-chair, TEAP	US
Maher Mousa, Member, RTOC	SA
Tetsuji Okada, Member, RTOC	J
Alaa Olama, Member, RTOC	EG
Fabio Polonara, Co-chair, RTOC	IT
Nihar Shah, Independent expert	IN
Rajendra Shende, Senior expert, TEAP	IN

* indicates Chapter Lead Author

TEAP would like to extend its appreciation to RTOC member Rajan Rajendran for the specific information he provided on the commercial refrigeration sector.

1.2.2 *Building on Previous TEAP Reports*

Energy efficiency (EE) is a broad topic of major importance for the environment, economics and health. There is an enormous amount of published literature and reviews focused on several energy consuming products and equipment, including refrigeration and air conditioning appliances and systems. In preparing its response to the decision, the Task Force referenced information provided in earlier TEAP reports (see below - Decision XXVIII/3 Working Group Report – October 2017, and Decision XXIX/10 Task Force Report – September 2018) and examined updated, available research and studies. The Task Force also performed market research based on on-line shops in several geographic regions, to have a more recent and practical assessment of the market.

The Twenty-Eighth Meeting of the Parties, following the adoption of the Kigali amendment, adopted decision XXVIII/3 on energy efficiency and requested the TEAP "to review energy efficiency opportunities in the refrigeration and air-conditioning and heat-pump sectors related to a transition to climate-friendly alternatives, including not-in-kind options". In response, TEAP established an internal Working Group to scope out the opportunities for energy efficiency gains in parallel with the HFC phase-down.

The Twenty-Ninth Meeting of the Parties adopted decision XXIX/10 and requested the TEAP to assess (in relation to maintaining and/or enhancing energy efficiency in the RACHP sectors) "technology options and requirements, including: (i) challenges for their uptake; (ii) their long-term sustainable performance and viability; and (iii) their environmental benefits in terms of CO2-eq; capacity-building and servicing sector requirements in the refrigeration and air-conditioning and heat-pump sectors; and related costs including capital and operating costs". It also requested the Panel to provide an overview of the activities and funding provided by other relevant institutions. In response, TEAP established a Task Force, with the inclusion of members with knowledge on the challenges of high ambient temperature (HAT) conditions.

The Thirtieth Meeting of the Parties adopted decision XXX/5, and in response, TEAP established the current Task Force. This Task Force includes many members of the previous task force ensuring continuity and consistency in TEAP's expertise and response on this topic, has a majority of A5 members (57%), good regional balance, and has increased input from members with expertise in HAT conditions.

The Task Force met on 22-23 February 2019 in Paris. This report was drafted and reviewed by the Task Force, and then by the TEAP prior to submission to the Ozone Secretariat.

1.1 Structure of the report

In this report, we have used the term energy efficient "technology" to include both lower GWP refrigerants and improved components (e.g. variable speed compressors, micro-channel heat exchangers, etc.). Domestic air conditioners and commercial refrigeration units, which are the focus of this report, use the vapor compression cycle as the dominant technology.

This report is organised into an introduction and four main chapters.

- **Chapter 1: Introduction**
  Scope of work, previous reports by TEAP, Task Force composition and organization,
  Chapter 2: Availability of low-GWP technologies and equipment that maintain or enhance energy efficiency
  The different types and stages of Availability of technology, equipment, refrigerants, and components are defined and mapped
- **Chapter 3: Costs of low-GWP technologies and equipment that maintain or enhance energy efficiency**

The costs of available medium and low GWP (or lower) refrigerants, technologies and components, assembly and finished products.

- **Chapter 4: Role of market in the availability of energy-efficient RAC equipment and low-GWP refrigerants**
  Policies that encourage and market barriers that impede the simultaneous transition to lower-GWP and higher efficiency equipment.
- **Chapter 5: Discussion.**

2 AVAILABILITY OF LOW-GWP TECHNOLOGIES AND EQUIPMENT THAT MAINTAIN OR ENHANCE ENERGY EFFICIENCY

Key messages:

General Considerations:

- Medium and low-GWP refrigerants are widely available and do not limit the demand for AC.
- AC and CR equipment meeting the minimum EE requirements in the respective countries are widely available for all refrigerant families including HCFCs; however, extremely limited development to achieve higher EE is taking place on HCFC equipment due to their phase-out schedules.
- Where markets and supporting policies provide clear signals towards alternative refrigerant choice, manufacturers invest in related R&D for those refrigerants while maintaining or enhancing energy efficiency. As a consequence, the R&D effort to develop energy efficient RAC (Refrigeration and Air Conditioning) equipment is being focused on lower GWP technologies. This is particularly visible in the HCFC-22 transition, where no manufacturers supply high-efficiency variable-speed air conditioners using HCFC-22. While the development of new efficient equipment with high GWP HFCs is still taking place in some regions, most effort is now being put into developing energy efficient equipment with medium- and low-GWP refrigerants that exceed the minimum EE ratings by 10% or more.
- Some components to enhance EE in use in AC and CR equipment with lower GWP refrigerants are not widely available[2]. Components for medium-GWP refrigerants are more widely available with some countries transforming the majority of their consumption to these refrigerants.
- Intellectual Property (IP): Most of the widely available new technologies contributing to higher EE equipment are not directly impacted by IP considerations. However, for technologies available from a limited number of suppliers, emerging technologies, or R&D technologies, the IP impact has to be determined on a case-by-case basis.

Air Conditioning equipment:

- HCFC-based AC generally has a lower EE, with no on-going R&D to improve EE.
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[2] This Report defines "availability" in 3 tiers: Low-tier: AC units which meet a regional or country required energy efficiency MEPS; Mid-tier: AC units which are up to 10% more efficient than the base MEPS; and High-tier: AC units which are at least 10% or higher than the base MEPS.

- Medium and lower GWP refrigerant-based AC is "available" in many parts of the world, but in some important markets (e.g. US, HAT countries) it remains an "new technology".

Air Conditioning components:

The most important factor in developing any new product is the availability of components, such as compressors and heat exchangers.

- Higher efficiency and inverter driven compressors are available and presently used (mostly used for rotary). There is very limited availability for two-stage compression
- China produces 60% of rotary compressors worldwide (200 million/year). Its production of variable speed compressors (inverter) has doubled in 5 years to 70 million/year. This has been driven by the introduction of Minimum Energy Performance Standards (MEPS) in many important markets.
- Heat exchangers are still mainly "fin and tube" type; there is a move to smaller tube diameters and to micro-channel exchangers.
- These higher EE components reduce the refrigerant charge and are valuable in enabling medium and lower GWP flammable refrigerant AC units to comply with safety standards. They are widely available and presently in use.

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- Self-Contained Commercial Refrigeration Equipment (SCCRE) units are diverse in design, construction and function. They are made on small to medium scale (100's to few thousand). They must have high reliability since they often contain perishable foods. The equipment design (vertical vs horizontal, doors) impacts the heat load.
- The refrigerants used in CR were previously limited to HCFC-22, R-404A and HFC-134a, but this is now changing with CO_2, hydrocarbon units using HFC-600a and HC-290, and with HFO blends (based on HFO-1234yf) being introduced in many countries.

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HAT considerations for Air conditioning and Commercial refrigeration

- Large-scale testing projects of AC prototypes using low- and medium-GWP refrigerants have identified several refrigerants which provide comparable efficiencies in HAT conditions. The MLF-funded PRAHA-II is re-testing optimized units, using efficient compressors and heat exchangers, which were rebuilt from the original prototypes used in PRAHA-I. The results should be available in late 2019.
- HAT conditions are not generally an issue for commercial refrigerators (SCCRE), which are often placed inside air-conditioned stores and shops. However, in Article 5 parties, SCCRE are sometimes placed outdoors to prevent additional heat load inside the building and this will impact performance due to HAT.

This chapter covers the availability of refrigerants, technologies and equipment related to maintaining or enhancing energy efficiency, the availability of components required to enable this technology, and the availability of the final products using these enhanced technologies. It also focuses on the availability of air conditioning and commercial refrigeration appliances, both from the point of view of the manufacturer (in production, in research and development (R&D) or as an emerging technology), and also for the consumer.

Availability can be enhanced by sustainability e.g. avoiding being locked into inefficient technologies or obsolete refrigerants. Availability can be reduced by import restrictions, taxes, or shipping/transport costs and other policies as described in Chapter 4.

In this report, the terms "technology", "components" and "after-sales service" are described as follows:

- **Technology**: includes the different types of refrigerants and applications for energy efficient end-products;
- **Components**: includes which components are part of energy efficient products;
- **After-sales servic**e: encompasses practices available to properly service and maintain new enhanced energy efficiency technologies.

The stages of technology availability are defined in this report as follows:

- **Widely available**: Can be obtained from more than one manufacturer, supplier, or retailer. Distribution networks are available.
- **Availabl**e: Can be obtained from at least one manufacturer.
- **Emerging technology**: Prototype available at pilot or demonstration stage. An emerging technology may become available at a later stage or might not make it to the available stage.
- **R&D**: Still in testing phase with promising results. It may be commercialized within five years after passing through the emerging technology stage.

2.1 Intellectual Property Considerations

Technology leaders invest significant resources to provide new products that meet or exceed energy efficiency regulations. Novel technologies that employ new components are usually covered by intellectual property (IP) rights. IP helps technology leaders regain some development costs so funds can be reinvested for future R&D that further improve EE.

Due to rapidly changing environmental requirements there has been an abundance of R&D in lower GWP refrigerants and technology, with subsequent IP generation. The patent coverage for a specific advanced technology may not be clear, take time to evaluate, and differ between jurisdictions (e.g. granted in one part of the world and not in another). Understanding how IP covers a certain technology and how it fits within a desired use may require considerable expertise, expense, time and commitment. There may be a need for licensing or royalty payment to one or several different IP holders to enable a technology or product to be manufactured. Clearly defining the scope of a patent and conditions on the use of the IP will speed up the process for using a new technology or product with the new technology.

Industry needs to work together to properly employ IP-covered technologies. Technology leaders who have IP need to clearly share their expectations with the industry regarding:

1. Who can use their technology,
2. How users can employ their technology, and
3. What compensation may be expected for their technology.

Similarly, technology users need to seek input from IP holders early in their development process to understand the potential cost/benefit analysis for using a given technology and then determine if the novel technology should be employed based on net payback. Without conducting proper due diligence for IP covered technology early during a market transition, the industry may not be able to employ the most EE enhancing technologies quickly.

Most of the widely available new technologies contributing to higher EE equipment are not directly affected by IP considerations. However, for technologies available from a limited number of suppliers, emerging technologies, or R&D technologies, the IP impact has to be determined on a case-by-case basis. There are instances where, for the humanitarian considerations, IP has been waived or softened (e.g Anti-AIDs drugs). Such waiver/relaxation in IP across the board or on case-by-case basis may ease the availability and affordability of low HFC technologies and equipment to A5 countries.

2.2 Air-Conditioners (AC): Availability of Technology and Equipment

The report reviews the availability of several air conditioner technologies. Window type AC units were excluded from the analysis because of the slow progression of EE enhancing technologies with this type of unit, and because their market share is declining. The availability of various technologies was evaluated and tabulated against the EE levels expressed as a percentage of the Minimum Energy Performance Standards (MEPS) in the respective countries surveyed.

MEPS specify the minimum level of energy performance that appliances, lighting and electrical equipment (products) must meet or exceed before they can be offered for sale or used for commercial purposes (ECOWAS 2016). MEPS may be mandatory for a range of products and are an effective way to increase the EE of products. MEPS express EE or energy performance using the following metrics across the world:

- **COP (Coefficient of Performance)** is the ratio of the heating capacity to the effective power input to the device at any given set of rating condition (ISO 5151:2017-7). It is expressed in Watts divided by the power input in Watts (unit-less measure);
- **EER (Energy Efficiency Ratio)** is the ratio of the total cooling capacity to the effective power input to the device at any given set of rating conditions (ISO 5151:2017-7). This ratio can either be in BTU per hour divided by power input Watts (BTU/h/W), or in Watt /Watt (W/W)[3].
- **SEER (Seasonal Energy Efficiency Ratio)** Ratio of cooling output divided by the electrical energy input, measured at full and part-load, and weighted to represent the

[3] BTU/h/W to W/W conversion factor: 3.412 BTU/h/W = 1 W/W.

overall performance of the device for the weather over a typical cooling season in each given country. An alternative name to SEER is the **Cooling Seasonal Performance Factor (CSPF)**. **Heating Seasonal Performance Factor (HSPF)** is used for heating mode.

- **APF (Annual Performance Factor)** is a metric used for reversible heat-pump room air conditioners that heat and cool. It represents heating and cooling capacity per kilowatt hour (kWh) over one year of use of an air conditioner under specific conditions.

The following types of AC units up to 17.5 kW capacity were reviewed:

- Ducted split or central AC units generally use ductwork or piping to provide cooled air to multiple conditioned spaces. These units typically contain a compressor, an internal unit (internal to dwelling) which houses the evaporator, and an external unit (external to dwelling) which houses the condenser. Some units can be run in reverse (heat pump mode) to also provide heating.
- Mini-splits (or ductless units) use a compressor and a condenser in a condensing unit external to the dwelling, and an indoor evaporating contained within the conditioned space, and connected by short pipework. Mini-splits only cool the needed space on demand.
- Packaged rooftop units contain all the components in one box. They are often placed on roof tops of building and the air is ducted to the conditioned space, thus the name "rooftop".

Several configurations of AC units were reviewed since the configurations employed impact EE:

- Fixed-speed units denote that the compressor operates at one set speed.
- Two-speed units operate the compressor at high or low speed. High speed to handle the higher ambient temperatures and low speed for the milder weather.
- Variable speed or inverter[4] units operate the compressor at variable speeds according to the load which increases the energy efficiency. According to three research studies completed in Brazil, inverter units using lower GWP refrigerants can save up to 67% energy compared to fixed speed units with high GWP R-410A (Daikin 2016)
- Variable refrigerant flow (VRF) AC offers flexible, energy-efficient heating and cooling through the ability of the system to vary and control the refrigerant flow through multiple evaporator coils and provide individual temperature control in different zones as required[5].

[4] A type of motor controller that drives an electric motor by varying the frequency and voltage supplied to the electric motor, also known as inverter.

[5] VRF units are typically more complex units which generally have a compressor, and condensing unit, but multiple evaporating units in separate conditioned spaces, employing a complex control system. The control system adjusts the refrigerant flow to achieve the desired air-conditioning for each of the different spaces being conditioned.

Regional availability:

In Tables 2.2 to 2.4, the availability of the various technologies was plotted against the MEPS from various regions in a tabulated form. Three tiers of MEPS were considered in separate tables:

- Table 1: Low-tier: AC units which meet a regional or country required energy efficiency MEPS;
- Table 2: Mid-tier: AC units which are up to 10% more efficient than the base MEPS;
- Table 3: High-tier: AC units which are at least 10% or higher than the base MEPS

Within each table, each column represents a class of refrigerant:

- ODS refrigerant i.e. HCFC-22
- High-GWP HFC refrigerants with a GWP greater than 750
- Medium and lower GWP refrigerants with a GWP less than 750 e.g. HFC-32, unsaturated HFC blends (HCFO, HFO), and hydrocarbons (HC-290).

Table 2.1: In each refrigerant category, the availability is represented according to the following colour coding: The table is divided by region, with specific countries mentioned where restrictions exist.

Widely available
Available technology
Emerging Technology
Not available

In countries with MEPS, HCFCs are mainly available in the lowest efficiency tier, just good enough to meet the MEPS criteria, with few exceptions. India does have HCFC units. Though India has HCFC units with 10% higher efficiency than the baseline MEPS, mini-split units in the mid-tier and high-tier efficiency are only available using R-410A, HFC-32, and HC-290. No HCFC units qualify for the higher efficiency grades (3-star and above) which are 13% more efficient than the MEPS. China still has HCFC units available in the mid efficiency tier.

High-GWP HFCs, mainly R-410A, are available everywhere in the low-tier. The table shows some of the technologies available in the various regions including 2-speed, variable speed inverter and VRF.

The availability of lower and medium GWP refrigerants is more variable. HFC-32 is available in all three tiers in Japan, thanks to their Top Runner Program (see Chapter 4.2.3), while HC-290 is available in the European Union, China and India. Recently Ghana imported 400 HC-290 units from China through a program setup by GIZ of Germany.

The “Rest of the World”(ROW) includes countries or regions that have not been specifically mentioned in the table most of which have low or no MEPS. Determining the availability across such a wide spectrum is difficult and can only be very general. Availability for ROW is defined when the technology is present in one country or region.

Tables 2.2, 2.3, and 2.4 show the following general observations:

- HCFC AC generally has a lower EE, with no on-going R&D to improve EE.
- High GWP refrigerant-based AC are available around the world across all tiers of EE.
- Medium and Low GWP AC is “available” in many parts of the world but in some important markets (e.g. US, HAT countries) it remains an “emerging technology”.

Table 2.2: Availability of Technology for AC: Energy Efficiency vs. refrigerants - Low Tier

	High GWP HCFCs	High GWP HFCs	Low and Med GWP Refrigerants
Low Tier Energy Efficiency: Meets MEPS	HAT: Available as locally manufactured and imported units	US: Mini-splits (R-410A, R-407C) US: VRF (R-410A, R-407C) US: Central AC 2-speed (R-410A, R-407C)	Japan: HFC-32 units are prevalent
	China: More than 80% equipment with HCFCs	EU: Mini-splits- (R-410A, R-407C) EU: VRF (R-410A, R407C) EU: Central AC 2-speed (R-410A, R-407C)	EU: HC-290 and HFC-32
	India: Available from local manufacturers. Import is not allowed	China: about 40% equipment with HFCs	India: HFC-32 and HC-290
	HAT & ROW: available as imported and locally manufactured units	HAT: R-410A units with fixed speed and variable speed, R-407C available, but phasing out	US: HFO units
		Japan: Manufactures units with HFCs for export	China: HC-290 and HFC-32 units Ghana: HC-290 units imported into the country in a program supported by GIZ
		Korea: R-410A system including ductless, mini-split and VRF	
		Indonesia: R-410A units are almost half the market	Brazil: HFC-32 units by one supplier ROW and HAT (Excluding Saudi): HFC-32 units available as locally manufactured or imported units
		Brazil & Latin America: R-410A both fixed speed and inverter units	HAT: Research on HC-290 and HFOs by local manufacturers R-454B accepted by Egypt OEMs
	No development or availability in non A5 countries or Korea	India: Not available in lower efficiencies Japan: Regulations do not support equipment development with HFCs	HAT: Saudi safety regulations does not currently allow safety certification of flammable refrigerants for residential applications.

Table 2.3: Availability of Technology for AC: Energy Efficiency vs. refrigerants - Mid Tier

	High GWP HCFCs	High GWP HFCs	Low and Med GWP Refrigerants
Mid-tier Energy Efficiency: up to 10% higher than MEPS	China: Less than 20% equipment with HCFCs India: Available from local manufacturers. Import is not allowed.	US: Mini-splits (R-410A, R-407C) US: VRF (R-410A, R407C) US: Central AC 2-speed (R-410A, R-407C) EU: Mini-splits (R-410A, R-407C) EU: VRF (R-410A, R407C) EU: Central AC 2-speed (R-410A, R-407C) China: about 60% equipment with HFCs HAT: R-410A with inverter Korea: R-410A system including ductless, mini-split system and VRF	Japan: "The top runner program" requires weighted average APF higher than the standard value. (for both domestic and commercial ACs) EU -Mini-splits -VRF and 2-speed EU Ecodesign (HC-290 and HFC-32) India: HFC-32and HC-290 units widely available commercially Indonesia: HFC-32 units are almost half the market
	HAT & ROW: available as locally manufactured or imported units from some manufacturers in some markets	Indonesia: 5% of the market are R-410A inverter ROW: Availability of R-410A units in some markets ROW: Availability of R-410A units in some markets India: available up to 3 Star in R-410A	China: Both HC-290 and HFC-32 by some manufacturers US-Mini-splits -VRV, 2-speed Brazil: HFC-32 inverter units by one supplier ROW and (HAT excluding Saudi) HFC-32 units as locally manufactured or imported
	No development or availability in non A-5 countries or Korea	Japan: Not Available	HAT: Research on HC-290 and HFOs by local manufacturers R-454B accepted by Egypt OEMs

Table 2.4: Availability of Technology for AC: Energy Efficiency vs. refrigerants - High Tier

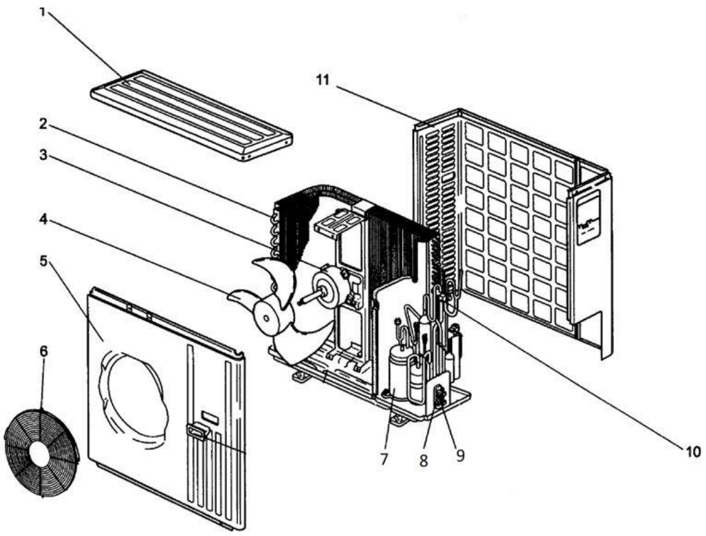
	High GWP HCFCs	High GWP HFCs	Low and Med GWP Refrigerants
High-tier Energy Efficiency: > 10% better than MEPS	India: HCFC-22 available in 3 Star. Only local units, imports not allowed	US: Central AC 2-soeed, Mini-splits, VRF with R-410A units	EU: Central AC 2-speed, Mini-splits, VRF, EU Ecodesign
	No development on high efficiency HCFCs. No availability in high efficiency	EU: Cent A/C 2-speed, Mini-splits, VRF-Ecodesign	Japan: "The top runner program" requires weighted average APF higher than the standard value. (for both domestic and commercial ACs)
		China: "Top Runner Program" requires weighted average APF higher than standard value, about 1% of market	India: HFC-32 and HC-290 available up to 5 Star
		Korea: R-410A system including ductless, mini-split system and VRF	China: one manufacture (Midea) have launched HC-290 and some manufacturers introduce HFC-32 that had higher APF than the standard value
		India: R-410A widely available in inverter 3 to 5 star	
		ROW: availability of R-410A units in some markets	ROW (and HAT excluding Saudi): HFC-32 units as locally manufactured or imported
		HAT: High GWP HFCs Could not meet higher efficiency with conventional design, however, MEPS >10%, (EER 12.7) can be achieved with microchannel heat exchangers	US: Emerging new technology using HFOs
		Japan: Not available	HAT: Research on HC-290 and HFOs by local manufacturers R-454B accepted by Egypt OEMs

2.3 AC: Availability of Components

The most important factor in developing any new product is the availability of components. Adopting new medium- and low-GWP refrigerants will require a specific re-design for many components.

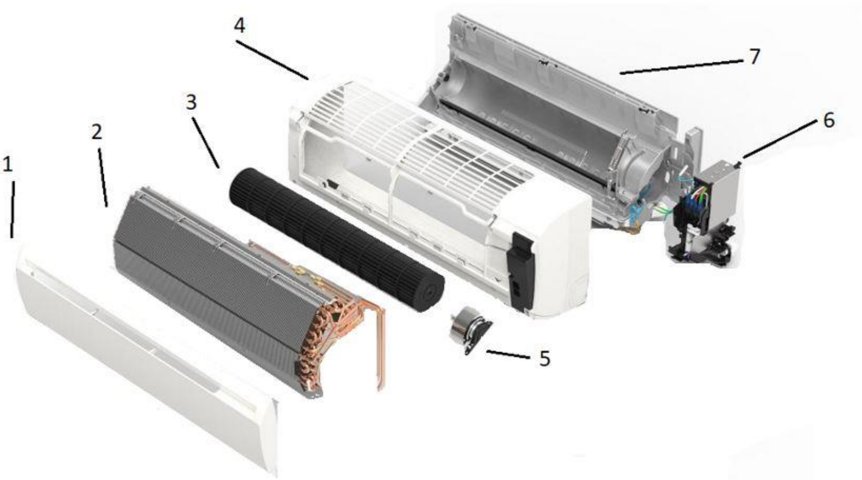
A ductless split unit consists of an outdoor unit and an indoor unit. The outdoor unit (Figure 2.1) is usually consisting of a compressor, a condenser coil and fan, an expansion device, and piping for liquid and suction lines. Other accessories can be added, as needed, for some applications (protection of the compressor or other parts). Even though these are considered optional features, their availability is important when considering new refrigerants as they might affect the overall EE.

The indoor unit (Figure 2.2) usually consists of an evaporator coil, a fan and a control system.



Legend	
1	Top Cover
2	Condenser Coil
3	Condenser Fan Motor
4	Condenser Fan Blade
5	Front Cover
6	Fan Grill
7	Compressor
8	Suction Line port
9	Liquid Line Port
10	4-way Valve
11	Back Cover

Figure 2.1: Outdoor unit components



Legend	
1	Front Cover
2	Evaporator Coil
3	Fan blade
4	Body Cover
5	Evaporator Fan Motor
6	Controller
7	Indoor Structure

Figure 2.2: Indoor unit components

This section addresses the availability of these main components and their effect on the EE of ACs. Table 2.5 below is a summary matrix for the component availability for medium- and low-GWP refrigerants for ACs. It is noteworthy that even though the majority of units are produced in China, the components are available from multiple sources.

Table 2.5: Availability of components related to EE for medium- and low-GWP refrigerants in AC. N = no; Y = yes; L = limited; X = applicable. LAT = Low Ambient Temperature, MAT = Medium ambient temperature, and HAT = High ambient temperature

Component	Applicable to ref circuit	Available today?	Presently in use?	Remarks	Necessary components	Max potential improvement	Incremental cost for RAC unit	Applicability to climate region		
								LAT	MAT	HAT
Compressors										
Higher efficiency	X	Y	Y	Mostly rotary compressor				X	X	X
-Inverter driven	X	Y	Y	Mostly used for rotary	Inverter, dedicated compressor	20% to 30%	20%	X	X	X
- two stage compression	X	Y	L	Very limited availability		10%	10% – 20%	X	X	X
- motor efficiency controllers		Y	L	Standard		same	Same	X	X	X
Energy efficient fan motors										
- EC fan motors		Y	Y	Reduce energy, heat load	Controller	7% to 15%	15% to 25%	X	X	X
- variable/fixed-speed		Y	Y					X	X	X
- optimized fan blades		Y	Y					X	X	X
-tangential fans		Y	Y	For indoor unit only				X	X	X
- improved axial fans		Y	Y	For outdoor unit only				X	X	X
Expansion devices										
- electronic expansion valves	X	Y	L		EEV and controller	15% to 20%	15%	X	X	X
-fixed orifice	X	Y	L		RAC heating	Less efficiency	negative	X	X	X
- capillary tubes	X	Y	Y		TEV	Heating mode	negative	X	X	X
Heat exchangers										
-Microchannel condenser coil	Y	Y	Y	Only condenser	AL/AL	15%	negative	X	X	X
-Microchannel evaporator coil	N	N	N				Less cost compared to the fin and tube			
- smaller tube diameter for condenser coil	X	Y	Y	Y	CU/AL	10% to 40%,	negative	X	X	X
- smaller tube diameter for evaporator coil		Y	Y	Y	CU/AL	10% to 40%	negative	X	X	X
Adiabatic condensers		Y	Very limited	Only in high	Filter and water	25% to 30%	20% to 35%			X

Component	Applicable to ref circuit	Available today?	Presently in use?	Remarks	Necessary components	Max potential improvement	Incremental cost for RAC unit	Applicability to climate region		
								LAT	MAT	HAT
				ambient	treatment					
Pipe insulation		Y	Y	Normal practice	Pipe insulation	<2%	Standard	X	X	X
Refrigerant	X	Y	Y	See RTOC 2014, 2018	Refrigerant	See RTOC 2014, 2018	+/- depends on the region	X	X	X
Defrost techniques	Y	Y		For HP only	controller		HP	X	X	X
- hot gas, reverse cycle		Y	L	HP	4 WAY VALVE	negative	Heating	X	X	X
- resistance heaters for Heating		Y	Y	some regions	Electric heater	negative	Some areas	X	X	X
- on demand control		Y	Y		controller		same	X	X	X
Controls										
- dynamic demand controllers		Y	Y		standard		standard	X	X	X
Reducing head pressure	X	Y	Y		Var speed cond. fans, controller	2 – 3% per 1 K	various		X	X

2.3.1 Availability of Refrigerants for AC

New refrigerants with flammability classes A2L and A3 create some challenges and require countries to include them in their local regulations[6]. HFC-32 and HC-290 can be obtained from several suppliers all over the world. The demand for HC-290 has been more-or-less stable and is covered by the present production. The same is true of HFC-32 although there has been an increase in demand lately. The demand for both refrigerants, however, remains small compared to R-410A.

[6] A2L are low flammable refrigerants, such as HFC-32 and A3 are refrigerants with high flammability, such as hydrocarbons (HC-290, etc.) Class A2 refrigerants are those with flammability in between A2L and A3 but as yet these refrigerants do not represent significant availability.

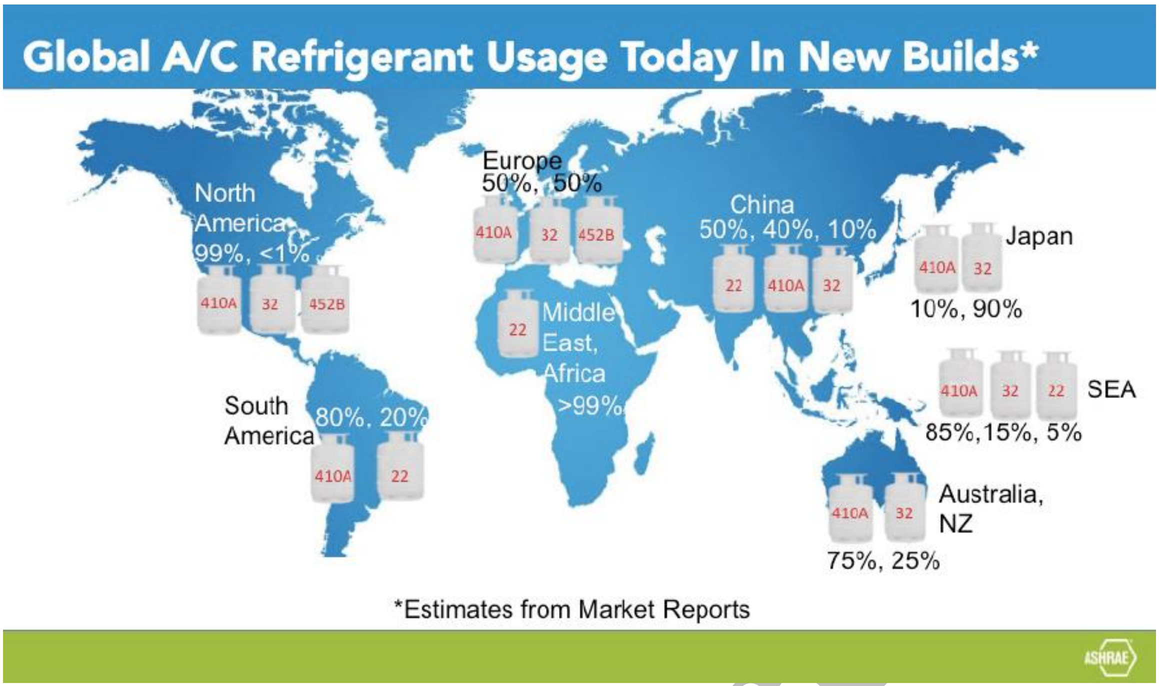


Figure 2.3. Global AC refrigerant usage in new unitary HVAC equipment. (©ASHRAE, www.ashrae.org, ASHRAE Webcast April 2019.).

As the production of AC using medium- and low-GWP refrigerants grows in Asia, especially in China, the long-term availability of these refrigerants is not likely to be an issue in terms of availability as the increase in refrigerant production would typically follow the increase in equipment demand.

2.3.2 Availability of Compressors for AC

The most common form of AC, mini-split ductless systems, mainly use rotary type compressors. The simplest form of rotary compressor is “fixed-speed,” meaning it only has two modes: “on” or “off”. It turns on to cool a room and turns off once the room has reached the desired set temperature. “Variable-speed” compressors are inverter-driven and can operate at more than one speed to more efficiently and comfortably deliver the amount of cooling needed and maintain the desired temperature. The variable-speed units require electronic control systems, which can add to manufacturing costs as described in Chapter 3.

Nearly all rotary compressor production is currently located in Asia and concentrated in China, as shown in Figure 2.1. Compressor manufacturing outside of China in descending order of capacity as of 2018 include Thailand, South Korea, Malaysia, Japan, India, Brazil, and the Czech Republic.

Figure 2.1: Global RAC Rotary Compressor capacity as at September 2018 (Nicholson et al 2019)

China is by far the world's largest producer of compressors for room AC, with an estimated annual capacity of nearly 200 million units per year. In 2018, the four largest compressor manufacturers in China together accounted for over 60% of global rotary compressor production capacity (Nicholson and Booten, 2019).

An analysis of company catalogues and websites found that rotary compressors using higher-GWP HCFC-22 and R-410A refrigerants accounted for the majority of models available worldwide in 2018, although many companies, mostly in Asia, now offer both fixed-speed and variable-speed compressors which use medium- and low-GWP HFC-32 and HC-290 refrigerants (Nicholson and Booten, 2019). However, the analysis found that none of the variable-speed compressor models identified use HCFC-22. In China, 42% of the 167 million rotary compressors produced in 2017 were of the variable-speed type, compared to five years earlier in 2012, when these were only 30% of 103 million (Figure 2.5) (Nicholson and Booten, 2019). Over 80% of the compressors produced in China are not exported; instead they are used in the domestic manufacturing of AC and later exported as final products or sold to consumers in China (Nicholson and Booten, 2019).

Approximately 30% of the rotary compressors produced in China in 2017 were designed to operate with the HCFC-22 refrigerant. While the quantity of HCFC-22 units has remained approximately constant over the past several years (Figure 2.6), the percentage of HCFC-22 units has declined in recent years, as the production of units using R-410A has increased to become the dominant type in China-produced rotary compressors (data from China IOL, as cited in Nicholson and Booten, 2019).

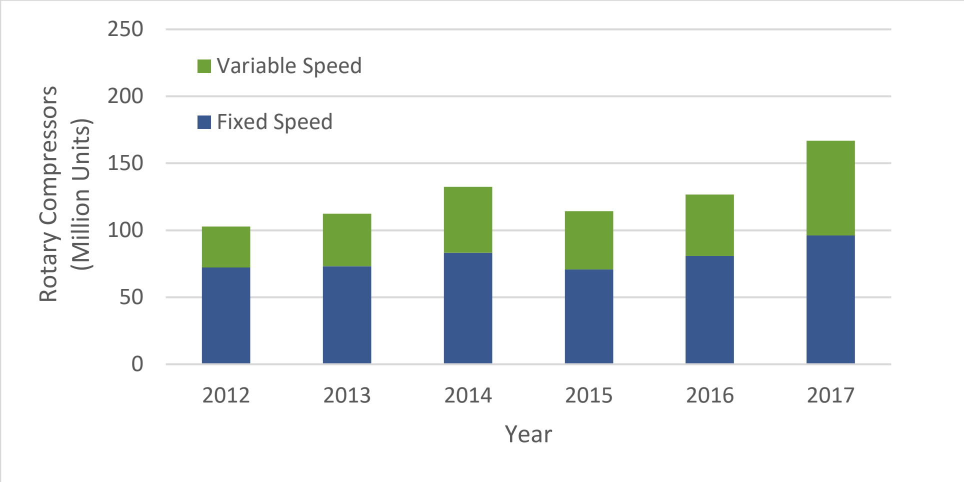


Figure 2.5: Chinese production of Fixed and Variable Speed Rotary Compressors, 2012-2017

Compressors for medium- and lower-GWP refrigerants (HFC-32 and HC-290) are mainly made in China.

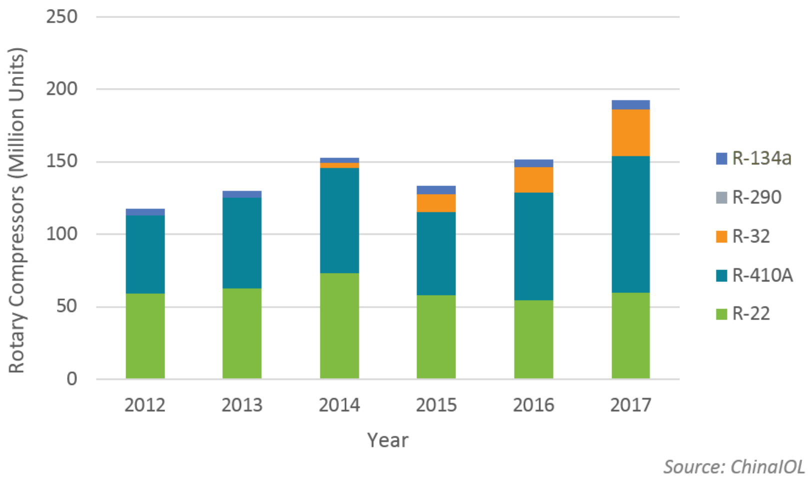


Figure 2.6: Chinese Production of Rotary Compressors by Refrigerant, 2012-2017(Nicholson and Booten, 2019). Note: HFC-134a rotary compressors are primarily used in mobile cooling applications, in contrast to the rest of the rotary compressor market which is used mainly for room (stationary) air conditioning

As can be seen from the chart, the production of HC-290 compressors is not significant compared to the other refrigerants.

Some Middle East countries, especially with HAT conditions, are still using reciprocating and scroll compressors in some of their production. Only a few rotary compressors are used for split air conditioning units.

The transition from fixed-speed to inverter compressors has sharply increased in the last five years to meet MEPS requirements, even though MEPS in some countries still list the full load efficiency figures only, rather than the seasonal efficiency figures. This is the case for Saudi Arabia where most of the AC units are fixed speed.

New compressor lubricants are being developed to be compatible with low-GWP synthetic refrigerants. Certain conventional polyester (POE) and polyvinyl ether (PVE) oils used for HFC refrigerants were insufficiently miscible with some refrigerants like HFC-32. New oils with better miscibility properties have been developed and patented for room AC use.

2.3.3 Availability of Heat Exchangers for AC

In most cases the heat exchangers continue to be of the “fin-and-tube” type made from copper or aluminum (more information on heat exchangers in section 3.2.3). However, many companies are switching to use smaller tube diameter and micro-channel heat exchangers, which are already used in existing high-GWP AC split units. The most commonly used heat exchanger tube diameter for standard high GWP refrigerant are 3/8 inch (9.525 mm), ¼ inch (6.35 mm), and 7mm (~1/4 inch) tube diameter, but for the new refrigerants, some companies are using tubes of 5 mm diameter. These higher energy efficiency components reduce the refrigerant charge and are valuable in enabling medium and lower GWP refrigerant AC units to comply with safety standards. They are widely available.

2.3.4 Availability of fans for AC

Each split unit contains two fans (one in the outdoor unit and one in the indoor unit). Fan technologies are widely available. There are no special requirements for using efficient fans for medium and lower-GWP refrigerants.

2.3.5 Availability of Refrigeration Accessories for AC

The accessories for the refrigeration circuit used in the split AC units include the expansion device, liquid and gas valves, suction accumulator, liquid receiver, oil separator (if needed), and all accessories installed in the connecting pipes between all major components of the AC unit either in the gas side or liquid side of the unit. All of these components and accessories are available for high-GWP refrigerant applications and can be used for the medium- and low-GWP applications.

2.4 Availability of Technology and Equipment for Commercial Refrigeration (CR)

Self-Contained Commercial Refrigeration Equipment (SCCRE) is a category of CR products that encompass the entire refrigeration system (compressors, expansion devices, evaporators, condensers and ancillaries) in one packaged unit. They are different from remote or centralised systems where condensers and other system parts are usually located away from the part involving cooling. Liquid-cooled SCCRE – where the entire product is integral, although it requires a connection between its condenser and a secondary circuit to remove heat – may also be considered to fall under this self-contained category, since the refrigerant circuit is still within the one package. Details of the equipment characteristics can be found in the latest RTOC Assessment Report (UNEP, 2018).

Some examples are shown in Figures 2.7-2.12.

Figure 2.7: Gondola type freezer

Figure 2.8: Multi-deck cabinet freezer

Figure 2.9: Ice cream freezer

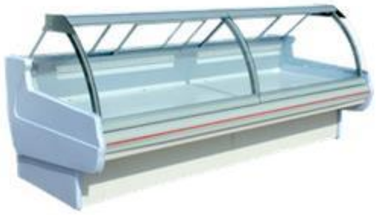


Figure 2.10: Serve-over display

Figure 2.11: Bottle cooler

Figure 2.12: Reach-in storage cabinet

Compared to air conditioners, there are several distinct differences in terms of SCCRE design, purpose and technological drivers. These aspects play an important part in terms of the technological options for SCCRE.

In particular, two of the main differences of SCCRE are:

- It is essential that systems operate continuously and reliably, since SCCRE often hold many thousands of USD worth of product and a failure of the system can result in product and financial loss;
- For perishable goods, product temperatures must be maintained, so that foodstuff remains edible and of sufficient quality (in terms of taste, texture, colour, etc.).

Functionality and construction of SCCRE differs widely, for example:

- Cooling operating temperature levels range from below -20°C (such as for ice cream) to over +10°C (for certain vegetables), with increments at -18°C, -2°C and +5°C;
- Configurations include vertical, horizontal, corner and combined orientations with open types, with doors, etc. and these construction characteristics have a strong influence on heat load and thus efficiency;
- The operation may be continuous or intermittent depending upon the purpose and may or may not use forced defrosting;
- Operating conditions vary widely according to the ambient conditions (e.g. in a professional kitchen temperatures can exceed 30°C).

SCCRE products are thus diverse in their design, construction and function, and products, accordingly range from small batch-level to “mass” manufacture. However, the majority of SCCRE are produced at small to medium scale, i.e., between 100 to the low thousands per model per year. This is dwarfed by orders of magnitude by hundreds of thousands to millions per year of AC models. Due to the relatively low production numbers and a wider range of product models, the degree of optimisation and fine-tuning of product performance seen with AC is seldom justifiable for small- to medium-scale SCCRE. In this way, individual product designs are tuned differently with different combinations of design features applied across the sector, although within an individual enterprise options are applied to as many models as possible

Unlike AC, “energy efficiency” is usually gauged in relation to the entire product and its elements.

- Room AC is typically evaluated in terms of operating efficiency (COP or EER) at a particular set of conditions and a specified heat (or cooling) load and accounts for energy use, including fan/motor sets and electronics. For AC the product efficiency is usually expressed as (electrical) energy use per unit of cooling (or heating) energy flow (kW per kW).
- SCCRE largely dictate their own heat load (thermal conduction, infiltration, product perspiration, defrost heat, fan/motors, etc.) and these, amongst other things, determines the energy use of the refrigeration system. SCCRE is usually expressed in terms of (electrical) energy use per unit of display area or per volumetric unit of storage space – all at a particular product target temperature. Thus SCCRE "energy efficiency" encompasses a wider variety of parameters.

The refrigerants used in commercial refrigeration were limited to HCFC-22, R-404A and HFC-134a. This is changing with CO_2, hydrocarbon units using HC-600a and HC-290, and with HFO blends (based on HFO-1234yf) being introduced in many countries. Table 2.6 below shows the percentage in mass of refrigerants used for commercial refrigeration in 2018 in China where 62% of refrigerant mass is low- and medium-GWP refrigerants and the units using those refrigerants exceed the minimum energy efficiency requirement (ChinaIOL 2018[7]).

Table 2.6: Percentage of units with different refrigerants for CR in China (ChinaIOL, 2018 and expert estimates). See Table 1 for colour coding.

	HCFCs	High GWP HFCs	Medium and Low GWP
Medium & High Tier: Higher than MEPS	Not available	HFC-134a = 11% R-404A = 23% Other HFCs = 4%	HC-600a = 10% HC-290 = 52% and increasing rapidly
Low Tier: Meets MEPS			Not Available

2.5 CR: Availability of Components

Table 2.7 lists technologies that could be used for improvement of SCCRE EE. A comprehensive description of options is provided in Foster et al. (2018). In Table 2.7, the technologies that are broadly influenced by refrigerant are identified (i.e., "applicable to ref circuit"). The majority provide a comparable level of EE benefit to many refrigerants. The cost

[7] http://blog.sina.cn/dpool/blog/s/blog_87e36f0f0102wpza.html

and energy benefit offered by each technology depends strongly upon the type of SCCRE. Additionally, it is identified whether the technology is available and/or in use today ("Available today?" and "Presently in use?"). Another column lists the type of SCCRE that the option is typically applicable to; in this respect the "maximum potential for EE improvement" and "indicative incremental cost" relates to the type(s) of SCCRE it is applicable to.

Columns "remarks" and "necessary components" provide an indication as to the equipment needed to implement the options.

The final three fields infer which of the climate categories the options are broadly applicable to; LAT, MAT and HAT. Indeed, almost all are applicable to virtually all climate categories, although in many cases the local humidity and fluctuations in temperature probably have more influence. The main categories are introduced below

2.5.1 Availability of Compressors

A variety of different compressors are used in SCCRE, depending upon temperature lift, capacity, refrigerant type, and so on.

For most types of compressors, efficiency improvements arise from marginal incremental refinements (such as oil distribution, valve losses, motor efficiency, internal leakage, flow path pressure losses, internal heat transfer, etc.). One major technological progression involves use and deployment of variable speed compressors, typically using inverter technology to enable the control of rotational speed over a fairly wide range. Variable speed compressors allow the mass flow of refrigerant to be adjusted to suit the cooling (or heating) demand so that the system components are essentially closer to the optimal balance point for the surrounding temperatures. Implicit in this is the lower mass flow (at sub-maximum load) which leads to reduced pressure losses and less frosting.

Usual compressors are hermetic reciprocating, scrolls and rotary (both vertical small print and horizontal when height restrictions apply)

The remaining compressor developments have arisen from the increased use of R744, where much higher pressures, pressure ratios and pressure differences are present, compared to usual refrigerants. Although many of these developments are in principle beneficial to other refrigerants, they result in a costly approach for minor efficiency improvements.

The applicability to a specific climate /region depends more on daily or annual variation in temperature, rather than absolute high or low temperature.

2.5.2 Improved cabinet air flow

Improved cabinet air flow has a potentially huge impact on energy use and also product quality. Various physical approaches are available such as changes to configuration of air ducting and small plastic baffles and plates. Most are broadly cost-neutral but just require extensive R&D.

2.5.3 Energy-efficient fan/motors

Major transformation has occurred in the shape of electronic commutation (EC) motors, which offer significant reduction in energy use. Further benefits arise from design of fan structure and blade shape.

2.5.4 Doors on cabinets

Intuitively the use of doors on display cabinets should yield major energy benefits by retaining cold air and preventing spillage and entrainment of warm humid air. Major improvements are associated with "vertical" type cabinets, where infiltration ordinarily contributes to about 70 – 80% of the heat load (ORNL, 2004). The benefits are less with gondola (also known as well or coffin) type cabinets where infiltration is responsible for about 20% of the load. Gaskets around glass doors also amplifies the benefit of using door (Rauss et al., 2008).

2.5.5 Cabinet lighting

Historically SCCRE used fluorescent lamps but presently LEDs are almost ubiquitous. LEDs use less power and also reduce heat output (thus reducing heat load).

2.5.6 Defrost techniques

Historically a variety of defrost techniques have been used, including reverse cycle, hot gas, cool gas as well as electrical resistance heaters on "off-cycle" where air is continued to be passed over the frosted coil but with absence of refrigeration. Whilst reverse cycle, hot gas and cool gas defrost offer more efficient defrosting, they tend to be more costly to implement and have other implications that affect system reliability, such as causing thermal shock and thus increasing leakage. The most beneficial development related to defrost is control methodology so that defrosting-on-demand can be applied.

2.5.7 Controls

In addition to improved cabinet airflow, and in parallel with variable speed compressor drives, the most significant contribution to SCCRE efficiency improvement has come from modern control technology. Application of the electronic expansion valve (EEV) and associated control software can yield substantial improvements in EE, although at present there is only limited application in SCCRE due to the relatively high cost, compared to other technologies. Control systems linking compressor modulation, EEVs, defrost-on-demand, lighting, trim-heaters, fan airflow rates as well as leak detection based on system parameters can have a major influence on energy consumption and optimisation of cycle efficiency. Adjusting the cooling to the use pattern e.g. while keeping the product at, say, 3°C if the shop is closed (such as during weekends, etc.). The set-point temperature can be adjusted to achieve the optimum balance between run time and pull-down energy demand. Such techniques are not applicable to perishable products.

2.5.8 Heat exchanger design

Features related to heat exchanger design are diverse and given the variation on SCCRE design, construction and function, it is difficult to make general statements on how much EE improvement particular approaches can offer and what the potential improvements could be. Target heat exchanger approach temperature difference should be below 5 K, for both evaporator and condenser. Often it depends upon the skill and knowledge of heat exchanger designers and manufacturers. In general, it is common practice today to use microchannel heat exchangers (MCHX) for condensers and brazed plate heat exchangers (BPHX) for liquid-cooled condensers, which simultaneously offer advantages in terms of charge reduction (preferred for flammable refrigerants). For smaller capacity units, wire-on-tube (WoT) condensers are used, which are low cost and provide sufficient levels of EE. The major advantage is however, that degradation due to dust accumulation over time is substantially.

2.5.9 Heat load

Lowering the heat load into the SCCRE helps reduce energy consumption per m^2 or per m^3 of refrigerated space, although it does not necessarily impact on the refrigeration cycle efficiency. Most approaches are based around limiting thermal transfer from electrical components, minimising radiant heat transfer from the surroundings and reducing conduction into the space.

2.5.10 Leak minimisation

Whilst leak minimisation is a priority for the application of flammable refrigerants, actions to retain the entire charge can significantly contribute to maintaining the “design” efficiency of a SCCRE. A deficit of refrigerant charge can go unnoticed until a certain level is reached, but in the meantime the compressor operates longer and cycle efficiency degrades.

Whilst many of these technologies can in isolation produce substantive improvements in EE, combining two or more technologies will not result in summation of both improvements. Considered selection and iteration of implementation is necessary to obtain the most cost-effective benefit.

Many of the “older” technologies are now becoming redundant since newer technologies help bypass the need for others. For example, locating fan motors outside the cabinet is no longer worth the effort, when new EC fan motors only emit a fraction of heat of previous fan types

National or regional MEPS are the main driver for improving EE. Historically “in-situ” direct testing of energy use was riddled with misinterpretation and misunderstanding of measurements and results. Increasingly more rigorous methods are being developed. However, one of the main challenges is conducting tests that mimic real life conditions, which can vary widely and drastically affect comparative results.

Regulators in certain regions have introduced MEPS. However, the process has been turbulent in many cases due to the basis (dominator) for determining energy consumption, i.e., per internal volume, per display area, etc.

Table 2.5: Overview of technical options for reducing energy consumption . Y: yes, N: no, X: applicable, LAT: Low ambient Temperature, MAT: Medium Ambient Temperature, HAT: High Ambient Temperature

Option	Applicable to ref circuit	Available today?	Presently in use?	Applicable to what SCCRE?	Remarks	Necessary component(s)	Max potential EE improvement of entire SCCRE	Indicative additional cost for SCCRE	Applicability to climate region		
									LAT	MAT	HAT
Anti-fogging glass		Y	Y	Glass door freezer	Avoids heating elements, as option	Surface treatments	Minimal	<5%		X	X
Improved cabinet air flow											
- air deflectors/guides		Y	Y	Open multideck	Reduces cold spillage	Aerofoils	15%	neg.	X	X	X
- shelf risers and weir plates		Y	Y	Open multideck	Reduces cold spillage	Plastic strips	4%	neg.	X	X	X
- short air curtains		Y	Y	Open multideck	Reduces cold spillage	Airflow design	30%	Neg.	X	X	X
- strip/night curtains		Y	Y	Open multideck	Reduces cold spillage	Clear plastic strips	60%	$100	X	X	X
Energy efficient fan/motors											
- EC fan motors		Y	Y	All types	Less energy & heat load	EC motors	10%	+15%	X	X	X

Option	Applicable to ref circuit	Available today?	Presently in use?	Applicable to what SCCRE?	Remarks	Necessary component(s)	Max potential EE improvement of entire SCCRE	Indicative additional cost for SCCRE	Applicability to climate region		
									LAT	MAT	HAT
- variable speed		Y	Y	All types	e.g., 2-speed fixed	Fan motor type	10%	+15%	X	X	X
- optimised fan blades		Y	Y	All types		None	5%	Neg.	X	X	X
- tangential fans		Y	Y	All types		Fan type	5%	<10%	X	X	X
- diagonal compact fans		Y	Y	All types	Match press dp of cabinet	Fan type	5%	<10%	X	X	X
- improved axial fans		Y	Y	All types		Fan type	5%	<10%	X	X	X
- fan motor outside cabinet		Y	N	Never used	Not worth it	None	n/k	Neg.	X	X	X
Cabinet doors											
- doors on cabinets		Y	Y	All types	Reduces heat load and infiltration	Doors	45%	$300 per m	X	X	X
- door gaskets		Y	Y	Standard for freezer	Reduces heat load and infiltration	Gaskets	15%	$30	X	X	X
Compressors											
- higher efficiency	X	Y	Y	All types	Increased by 20% over past 20 years	Advanced compressor	20% (MT), 30% (LT)	Neg.???	X	X	X
- Inverter driven	X	Y	Y	All types	Better PL efficiency; with/out PFC	Inverter, dedicated compr	40%	2 × non-inverter	X	X	X
- motor efficiency controllers		Y	L	All types	Regions having poor mains power; not needed for VSD	MEC device	10%	n/k	X	X	X
- two stage compression	X	Y	L	Mainly for R744		Two (smaller) compr; two roller rotaries	5%	20 – 40%	X	X	X
- economisers/inter-stage coolers	X	Y	L	Mainly for R744		Special compressor + flash vessel or HX	15%	n/k	X	X	X
Expanders	X	Y	L	Mainly for R744		Expander / integragr compressor-expander	30%	n/a	X	X	X
Cabinet lighting											

Option	Applicable to ref circuit	Available today?	Presently in use?	Applicable to what SCCRE?	Remarks	Necessary component(s)	Max potential EE improvement of entire SCCRE	Indicative additional cost for SCCRE	Applicability to climate region		
									LAT	MAT	HAT
- LEDs		Y	Y	All types	Now standard	LED lamps	50% on lighting	<0%	X	X	X
- occupancy sensors		Y	Y	mainly for non-perishables	On demand lighting	Proximity sensors	10%	<0%	X	X	X
Defrost techniques											
- hot gas, reverse cycle		Y	L	Freezers, shortens time, product quality	Increases leaks, faults	Valve	5%	3%	X	X	X
- resistance heaters		Y	Y	MT and LT cabinets	Preferred/reliable	Heater rods	n/a	n/a	X	X	X
- off-cycle		Y	Y	HT and MT cabinets	Eliminates defrost energy	none	10%	<0%	X	X	X
- on demand control		Y	Y	All types	Defrosts when needed	Sensors, controller	10%	<5%	X	X	X
Controls											
- dual port TEV (balanced)	X	Y	N	Open type	Evens evap load	TEV	n/k	n/k	X	X	X
- dynamic demand controllers		Y	Y	All types	Manages energy use	Sensors & controller	40%	Various	X	X	X
- electronic expansion valves	X	Y	L	Larger cabinets	Modulates evap pressure	EEV and controller	20%	$200	X	X	X
- optimisation of capillary	X	Y	Y	All cabinets			Anything	Neg.	X	X	X
- suction pressure control	X	Y	L	Larger systems	Modulates evap pressure	(See VSC & EEV)	2% per K increase	$40 - $400	X	X	X
Reducing head pressure	X	Y	Y	Larger systems	Reduces press lift	Var speed cond fans, controller	2 – 4% per 1 K reduction	Various		X	X
Ejectors	X	Y	L	Larger systems, R744 only		Ejector valve	20% or 30% with R744	$20		X	X
Heat exchanger design											
- optimised configuration	X	Y	Y	All types	Better HT, lower DP	HX materials	0 to 40%, fn baseline	Neg	X	X	X

Option	Applicable to ref circuit	Available today?	Presently in use?	Applicable to what SCCRE?	Remarks	Necessary component(s)	Max potential EE improvement of entire SCCRE	Indicative additional cost for SCCRE	Applicability to climate region		
									LAT	MAT	HAT
- optimised air fins		Y	Y	All types	Better HT, lower DP	HX design	10%	Neg	X	X	X
- internal rifling	X	Y	Y	All types	Better HT, lower DP	HX design	5%	Neg	X	X	X
- internal fins	X	Y	Y	All types	Better HT, lower DP	Internal fins	5%	Neg	X	X	X
- hydrophobic coating		Y	L	All types	Mainly for conds, reduces dust and corr	Coating	5%	Neg	X	X	X
- hydrophilic coating		Y	L	All types, evaporators	Anti-corrosion; reduce water lyr thickness	Coating	5%	Neg	X	X	X
- flooded evaporators	X	Y	N	Larger systems	added to R744	Float v, surge drum	5%	n/a	X	X	X
Other heat load											
- radiant reflectors		Y	Y	Any glass	Reflects IR	Internal surface	8%	Neg	X	X	X
- night blinds and covers		Y	Y	All types	Can reduce IR and infil	Night blinds, covers	20%	$300	X	X	X
- improved glazing		Y	Y	Any glass	Reflects IR	New glass	5%	5%	X	X	X
- anti-sweat heater control		Y	Y	Any with AS heaters	Minimise heat load	Controller, sensors	3%	Neg.	X	X	X
- refrigerant line trim heaters		Y	Y	LT cabinets	Instead of resistance heaters	Extra piping	10% to 25%	Neg.		X	X
- vacuum insulated panels (VIP)		Y	N	All types	Reduces thermal cond	VIP	15%[8]	$400/m^2	X	X	X
Heat pipes		Y	N	All types	In cabinet shelves, improv product temp	Integrated heat pipes	12%	n/k	X	X	X
Leak minimisation											

[8] Clodic and Zoughaib (2000)

Option	Applicable to ref circuit	Available today?	Presently in use?	Applicable to what SCCRE?	Remarks	Necessary component(s)	Max potential EE improvement of entire SCCRE	Indicative additional cost for SCCRE	Applicability to climate region		
									LAT	MAT	HAT
- improved leak tightness	Y	Y	Y	All types	Degrees of improvement	Manufacturing kit	20%	10%	X	X	X
- leak detection	Y	Y	L	All types	Previously on large sys	Sensors	15%	10%	X	X	X
Liquid pressure amplification	X	Y	N	Larger systems		Liquid pump	25%	30% of compressor cost	X	X	X
Liquid-suction HX	X	Y	Y	All types	Brazing pipes together	LSHX	0%	Various	X	X	X
Pipe insulation		Y	Y	All types	Normal practice	Pipe insulation	3%	n/k		X	X
Higher efficiency refrigerant	X	Y	Y	All types	See RTOC 2014, 2018	Refrigerant	See RTOC 2014, 2018	+/-	X	X	(X)
Nanoparticles in refrigerant	X	Y	N	All types	Experimental, concerns	nanoparticles	20%	\$20 – 100	X	X	X

2.6 The impact of ambient temperatures on availability of suitable AC equipment

The impact of ambient temperature on energy efficiency is well documented. As the ambient temperature increases, the capacity output of an AC unit decreases and the power input increases. TEAP working group report on energy efficiency (TEAP 2018) discussed in detail the effect, especially in high ambient temperature (HAT) conditions.

The temperature impact on the thermodynamic behaviour of refrigerants is related to the critical temperature of the refrigerant. Refrigerants with lower critical temperatures have lower efficiencies as ambient temperatures approach the critical temperature. This is the case for R-410A where units with the same technology and similar components will demonstrate lower efficiency than HCFC-22.

There is debate on which high temperatures should be adopted for tests measuring energy consumption used to define the MEPS. ISO defines three temperature: 27°C, 35°C, and 46°C referred to as T2, T1, and T3. Most countries adopt T1; however, for climates higher than 35°C countries want their MEPS to reflect this reality and units to be rated at T3.

There is no discussion about any issues for low ambient temperature (LAT). When discussing component availability for RAC and commercial refrigeration, the distinction was made for three climate zones: LAT, MAT (medium ambient temperature), and HAT. LAT was defined as ambient up to 27°C and MAT is between 28 and 35°C. HAT is 35°C and above, as defined by the Parties of the Montreal Protocol.

Table 2.7 shows that most of the higher efficiency components are relevant for all three of the defined climate zones, except for LAT, where adiabatic condensers are not needed.

2.6.1 HAT Considerations

The discussion about suitability of refrigerants for HAT condition has led to several large-scale testing projects where prototypes using low and medium GWP refrigerants were built and tested at ambient exceeding 35°C. The outcome of these tests (TEAP 2018) was the identification of several refrigerants, which provide comparable efficiencies in HAT conditions. PRAHA, which is an MLF funded program, is in its second phase (PRAHA-II). It is re-testing optimised units using efficient compressors and heat exchangers, which were rebuilt from the original prototypes used in PRAHA-I. The results should be available in late 2019.

HAT conditions are not generally an issue for commercial refrigerators (SCCRE), which are often placed inside air-conditioned stores and shops. However, in developing countries, SCCRE are sometimes placed outdoors to prevent additional heat load inside the building and this will impact performance. Industry leaders have experienced that in HAT conditions the indoor ambient temperature is approximatively 5°C higher than the indoor ambient temperature in non-HAT conditions (Topten unpublished data). This increased temperature is however not sufficient to have an impact on the product’s EE.

3 COST OF LOW-GWP TECHNOLOGIES AND EQUIPMENT THAT MAINTAIN OR ENHANCE ENERGY EFFICIENCY

Key messages:

- Local industries in A5 parties with AC manufacturing or assembly plants may need financial assistance to convert facilities for safe use of flammable refrigerants, and to in-license technological advances for EE.
- A transition from manufacturing RAC equipment from low to high flammability refrigerants (high to low GWP), requires additional capital and operating costs.
- There are additional capital and operating costs for conversion of manufacturing to flammable refrigerants, and at the same time to incorporate technology for energy efficiency. The Task Force has provided detailed estimates of the additional costs
- Refrigerant cost accounts for ~1% of the overall RAC equipment cost. It is predicted that HFC costs will rise as phasedown progresses and this will make low GWP refrigerants increasingly cost-competitive.
- Compressors account for ~20% of the cost of RAC equipment. Efficiency can be improved by up to 20% by technical advances, but cost increases proportionately.
- Heat exchangers of the "fin and tube" type have improved their efficiency with the introduction of small diameter tubes. Most recently the switch to micro-channel heat exchangers has been accelerating – they have similar or marginally lower cost (~5%) and up to 5% higher efficiency. They reduce the refrigerant charge by ~40%
- Optimising airflow improves EE. The power and cost of fans increase in a stepwise fashion, leading to a complex relationship between increasing cost and EE. The cost effectiveness for optimal EE is determined on a case-by-case basis.
- Other technologies including self-cleaning to reduce dust deposition are a marginal cost.
- At any given time ("snapshot") there is a level of efficiency above where Life Cycle Cost analysis indicates for both AC and CR, that there is a ceiling of efficiency, above which the energy savings will not payback the higher capital cost within the lifetime of the equipment. As the cost for efficient components and designs decrease over time due to increases in scale of production or learning, the cost of higher efficiency equipment decreases. As this occurs, higher levels of efficiency payback over shorter periods.

The Task Force has estimated the additional capital cost required for the manufacturing equipment using a flammable refrigerant, in comparison to the two baseline refrigerants R-410A and HCFC-22 for mini-split AC units up to 10 kW (cooling/heating) capacity and the baseline HCFC-22 for Self-Contained Commercial Refrigeration Equipment (SCCRE).

The principles of upgrading a CR facility for flammable refrigerants are the same as for the manufacture/assembly of air conditioners. However, the larger scale manufacturing for AC will have different financial implications and payback periods.

The relative cost of the refrigerant itself is negligible, when compared to the overall cost of the AC equipment itself.

3.1 RAC manufacturing costs (including costs for the manufacturer to upgrade a production line)

Table 3.1 provides estimates of the range of costs for modifications required to change a manufacturing facility from high-GWP refrigerant to medium- and low-GWP refrigerants that are designated as flammable; low flammability class (A2L), flammable (A2) and high flammability class (A3) refrigerants. A single table has been presented as this captures the range for all flammability classes. They include:

1. The additional cost for production line equipment modifications/ replacements (such as refrigerant recovery and charging machines), refrigerant storage tanks, high pressure testing equipment, modifications on refrigerant charging area (including all electrical panels, piping and accessories), finished product testing areas, etc.;
2. The additional safety requirements for the new manufacturing processes using the flammable refrigerant including the safety ventilation system, safety control system, leak detection system, anti-static floor surfaces, fire-fighting system, etc.;
3. The shipping and the logistics required for importing components and or partially assembled products to the manufacturing facilities along with additional cost of storage of flammable refrigerant and the finished products;
4. The know-how and IP and design/software development costs; and
5. The installation and certification of new equipment, and training of personnel.

As with other cost quantifications, evaluating for upgrade of production is equally complex and is dependent upon the current set up, the size of the area, production capacity, type of equipment produced, safety concepts adopted by the production equipment supplier and so on. Relative additional costs are also highly dependent upon the production numbers.

Specifically, in Table 3.1, an additional cost is given for heat exchanger (HX) production tooling. In principle, if an already suitable HX is being used, there should be no impact on production cost. However, if for example, current HXs are made with large diameter tubes (e.g., >7 or10 mm) then adopting small diameter tube HX (e.g., <6 mm diameter) or indeed micro-channel HX (usually drawn aluminium type) then a significant cost may be incurred (depending upon the current production equipment). Critically there can be reductions in additional operating costs when switching from large diameter to smaller tubes (finned tube or microchannel HX) due to the reduction in material costs (copper or copper to aluminium), which should always be taken into account.

For several items/sub-items, costs listed are “variable”. This means that the likely cost is very sensitive to the aspects identified above (current set-up, size of production, etc.) so any number assigned is likely to be wrong.

Table 3.1: Task Force estimates of maximum additional cost to convert from R-410A or HCFC-22 (high GWP, non-flammable) manufacturing lines to flammable refrigerants

Item Description[9]	Sub-Item	Max additional cost % over the baseline refrigerants
Production/Assembly line Changes	Heat exchanger equipment for smaller tubing for better EE[10,†]	100%
	Refrigerant charging units	30%
	Testing area changes (electrical panels, piping accessories)	30%
	Charging area changes including refrigerant tanks and accessories	100%
	Refrigerant distribution within the plant	100%
	Labour cost	15%
Safety Requirements For charging and testing area	Ventilation system	30%
	Control system	30%
	Leak detection system	30%
	Anti-static floor	Variable
	Labour cost for O&M for safety system	Variable
IP/Technology know-how cost	IP / know-how cost	Variable
	Design-software development[†]	Variable
	Testing facility modifications and changes	50%
	Training the employees for safety requirements	10%
	External consultants and experts[†]	Variable
Logistics and Handling	Storage area for flammable refrigerants modification changes cost	200%
	Shipping cost in land and sea freight	Variable
	Refrigerant distribution within the plant	Variable
	Extra cost for insurance for factory and employees	Variable
	Certification cost for regulatory bodies	20%
	Training for employees	30%
	Training for jurisdiction party(s)	30%
	Awareness in/out the company	30%

[†] provides opportunity for energy efficiency (highlighted cells)

Colbourne et al. 2011 suggested that the distinct cost increase associated with the use of HC-290 over HCFC-22 or R-410A is in the order of €105,000 to €200,000 (24.4% to 25.3%) and is primarily due to the need for additional safety equipment associated with handling flammability. They also estimate that this results in an additional cost per unit output of €0.20

[9] Some sub- items are not required in the manufacturing lines for R-410A refrigerant

[10] The heat exchanger with smaller tube diameter can be used in both R-410A and HFC-32 refrigerants

at most assuming 250,000 units produced annually. There may be additional costs related to production line machinery.

In both cases for AC and CR, once the manufacturing line and facility have undergone conversion, there will be moderate additional operating costs including for example, the employment of higher-grade staff and higher shipping costs.

3.1.1 Manufacturing

Production line

Production line changes and additional requirements (modifications) to produce domestic AC units with flammable refrigerants will require production line equipment modifications and or replacements on each line including:

- Refrigerant recovery and charging machines for both A2L and A3 refrigerants (25,000 - 50,000 USD)
- Pressure testing equipment for high pressure refrigerant A2L (HFC-32) (15,000-30,000 USD)
- Refrigerant storage tank and accessories (3000 to 10000 Litre) 15,000 - 40,000 USD)
- Structural and safety modifications in the refrigerant charging area (including electrical panels, piping, anti-static floors and accessories) (15,000 - 25,000 USD)
- Modifications to the finished product testing areas (10,000 - 20,000 USD)
- Modifications for heat exchanger production line for tooling for smaller tube diameter, or establishment of new production lines for micro-channel heat exchanger (1,000,000 - 1,500,000 USD). It should be noted that smaller diameter or microchannel heat exchanger, the material cost is significantly reduced.
- Labour costs differ between countries, but extra costs will come in two main categories:
    1. Staff training to build capacity in dealing with flammable refrigerants and their safety requirements.
    2. Additional staff cost to use more skilled workers.

The estimated cost for these items varies between countries and depends on the source of the equipment and availability of parts. For example, the cost of a refrigerant charging machine from China is 30% lower than buying the same specification machine from Europe (in the range 25,000 - 50,000 USD). There is additional cost in the finished product testing area for flammable refrigerant compared to non-flammable refrigerants, due to the additional piping, isolation valves and gas leakage sensors (5 to 10 sensors at ~ 500 USD each) that are required in many locations. Figure 3.1 shows an example of a leakage sensor and control system installed in a laboratory area.

Figure 3.1: Control Alarm Panel and HC-290 sensors

Safety measures

Additional ventilation and fire-fighting equipment is required in the charging area, for safe manufacture any units for either A2L or A3 refrigerants with estimated costs as follows:

- Charging area ventilation system (10,000 - 20,000 USD)
- Charging area firefighting system including sprinklers and water storage tanks (20,000 - 30,000 USD)

Testing

Testing facilities are required at two locations, the production line and the laboratory for testing A2L and/or A3 refrigerants with the following estimated costs:

- The production line testing area (50,000 - 75,000 USD)
- The laboratory for product development (50,000 - 75,000 USD)

IP/technology know-how

The costs of technology transfer including IP and know-how are estimated as follows:

- Software (either developed in-house or outsourced from another specialized company: (0 - 50,000 USD)
- Building prototype(s) to verify performance and validate the software: (10,000 - 20,000 USD)
- IP cost is unknown but may be a royalty or a one-off license payment. For many A2L refrigerants there is substantial IP in terms of design of the refrigerant supply but moreover for system design, etc. With A3 refrigerants there is only very limited IP and this is generally associated with “gadgets” and are thus not critical to their application.

3.1.2 Logistics

Shipping

This will include the additional shipping cost due to flammability for all material and/or components required for the manufacturing of the AC and CR equipment, and the additional cost of shipping finished goods either internally or abroad.

This differs between countries. As an example, the shipping cost of a 40 ft container of flammable refrigerant from China to Jordan is 1,900 USD compared to 1,500 USD for non-flammable refrigerant. Some countries customs and clearance processes cost an additional 3-5%.

Handling

This includes the cost of handling and storage of the flammable refrigerant and or finished product inside the manufacturing facilities and preparing it for inland, sea and air freight shipments.

The handling process inside the factory requires the following precautions which increase the cost including:

- Storage of flammable refrigerant can be either inside a storage tank or smaller refrigerant cylinders, but both need adequate ventilation, and leakage monitoring systems: (20,000 - 30,000 USD)
- Handling the refrigerant and finished products inside the factory requires additional safety measures for transportation between the production departments and storage areas: (10,000- 15,000 USD)
- Additional factory insurance and product liability insurance for flammable refrigerants: (8,000 - 20,000 USD)

3.1.3 Installation

This will include the additional costs of the training and awareness programs under the local jurisdiction; the extra cost of the certification and approvals from the jurisdiction party(s) to comply with the local building codes; international certification requirements to meet safety standards required in many countries for in the domestic A/C and commercial refrigeration equipment using flammable refrigerants.

This can be in different categories with the following estimates for costs:

- Training and awareness programmes with certification of workers, workshops etc. (10,000 - 20,000 USD)
- The certification cost for the new products (depending on the number of models needing to be certified, and the test standards requirements IEC, ISO, etc. (10,000 - 15,000 USD)

3.1.4 Overall costs summary

In summary, the overall costs are shown in Table 3.2 (excluding shipping costs).

- The investment required to convert an RAC manufacturing facility to flammable refrigerants is in the range of 400,000 – 500,000 USD.
- The additional investment required to maximise energy efficiency by the establishment of new production lines for micro-channel heat exchangers is in the range 1,000,000 - 1,500,000 USD

Table 3.2: Estimates of the manufacturing costs for energy efficient RAC equipment containing low- and medium-GWP flammable refrigerants.

Conversion measure (USD)	Minimum	Maximum
Manufacturing		
Production line		
Refrigerant recovery and charging machines for both A2L and A3 refrigerants	25,000	50,000

Pressure testing equipment for high pressure refrigerant A2L (HFC-32)	15,000	30,000
Refrigerant storage tank and accessories (3000 to 10000 Litre)	15,000	40,000
Structural and safety modifications in the refrigerant charging area (including electrical panels, piping, anti-static floors and accessories)	15,000	25,000
Modifications to the finished product testing areas	10,000	20,000
Modifications for heat exchanger production line for tooling for smaller tube diameter, or establishment of new production lines for micro-channel heat exchanger	1,000,000	1,500,000
Safety measures		
Charging area ventilation system	10,000	20,000
Charging area firefighting system including sprinklers and water storage tanks	20,000	30,000
Testing		
Production line testing area	50,000	75,000
Laboratory for product development	50,000	75,000
IP/technology know-how		
Software	0	50,000
Building prototype(s) to verify performance and validate the software	10,000	20,000
IP costs	variable	variable
Logistics		
Shipping		
Additional costs	3%	5%
Handling		
Storage of flammable refrigerant can be either inside a storage tank or smaller refrigerant cylinders, but both need adequate ventilation, and leakage monitoring systems	20,000	30,000
Handling the refrigerant and finished products inside the factory requires additional safety measures for transportation between the production departments and storage areas	10,000	15,000
Additional factory insurance and product liability insurance for flammable refrigerants	8,000	20,000
Installation		
Training and awareness programmes with certification of workers, workshops	10,000	20,000
Certification cost for the new products (depending on the number of models needing to be certified, and the test standards requirements IEC, ISO)	10,000	15,000
Total without micro-channel heat exchanger production line or shipping) **Total with microchannel heat exchanger production line (excluding shipping) (USD)**	**303,000** **1,300,000**	**535,000** **2,035,000**

3.2 AC: The Cost of Components

The relative costs of energy efficient components are compared for a 3.5 kW mini-split in China. The baseline uses R-410A (APF 4.0) and HCFC-22 (EER 3.5) appliances. Certain components discussed in the following sub-chapter also apply to commercial refrigeration. These components will not be discussed in the chapter 3.3.

3.2.1 Refrigerant

Conventional refrigerants account for about 1% of the total AC cost. The price of refrigerant always decreases with increasing consumption. Indicative prices of refrigerants commonly used in air conditioning in China are shown in Fig 1. It is worth noting that in UK, the bulk HC (HC-290, HC-600a, HC-1270) price varies between USD 1 to USD 1.5 per kg. Furthermore, the average HCFC-22 price is USD 6/kg.

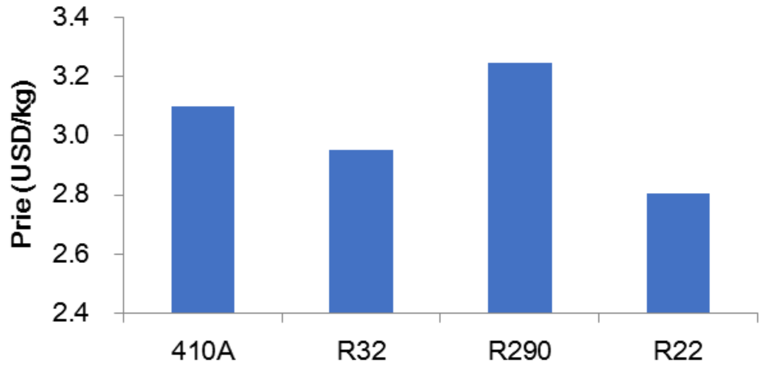


Figure 3.2: Estimates of refrigerant prices in China

The general price range of refrigerants is low, around 3 USD/kg +/-10%. At an early stage, new refrigerants are more expensive, and difficult to get a foothold in the market. For example, HC-290 is a by-product of the liquified natural gas (LNG) industry. Its production process is simpler than HFC-32, but its current price is slightly higher than HFC-32. However, when buying in bulk quantities, refrigerant-grade propane can be as low as $1 per kg.

The cost of high-GWP HFCs will rise with the implementation of the F-gas regulation and Kigali amendment, both of which impact the competitiveness of products containing HFCs. For example, the quoted price of R-410A in Europe went up tenfold over 2017, and in 2018 is ~ 20 Euro/kg, which far exceeds the material cost of the refrigerant itself (Figure 3.3). This increases the competitiveness of medium- and low-GWP alternative refrigerants and greatly promote the commercialisation of environmentally friendly refrigerant technologies.

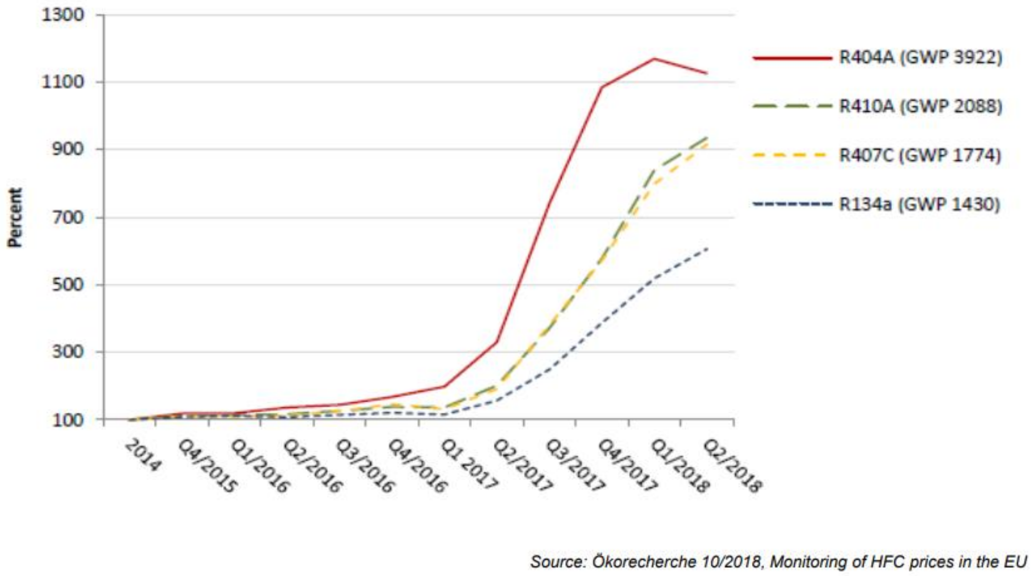


Figure 3.3: HFCs quota price trend in Europe (Ökorecherche, 2018)

3.2.2 Compressor

The compressor accounts for about 20% of the total cost of AC systems. Improving compressor efficiency represents one of the most direct and effective measure to improve an air conditioner's efficiency. Rotary compressors are the most commonly used. Piston compressors are used in some window air conditioners especially in the Middle East, whilst scroll compressors are often used in lighter commercial products. Today, modern compressors have an efficiency of about 70%. The majority of the losses are electrical and mechanical, with the remainder due to internal refrigerant leakage (Tello-Oquendo et al., 2018).

The most effective way to improve the efficiency of a compressor is to use a higher efficiency motor, but lower scale improvements can also be obtained using refrigerants with properties that provide higher thermodynamic efficiency, reducing inner leakage and mechanical friction. These will increase the cost of materials and manufacturing costs. Efficiency can be improved by up to 20% by technical advances, but cost increases proportionately (Task Force estimates): efficiency can be improved by up to 15% at additional cost increase of 20% through technical advances.

3.2.3 Heat exchangers

Finned tubes are the most commonly used heat exchangers for AC. The heat exchanger efficiency is mainly determined by the heat transfer coefficient, area and the flow friction and has a major impact on the system's cooling/heating capacity. The smaller the heat transferring temperature difference (i.e. the larger heat transferring coefficient multiplied by the area) and the smaller the flow friction, the higher the heat exchanger efficiency, which can be achieved. Measures to improve efficiency include heat transferring enhanced copper tubes and fins, increasing air volume, reducing contact thermal resistance between fins and copper tubes, improving manufacturing processing to reduce the damage to the heat transfer enhancing structure, and increase of the surface area and to improve the contact between tubes and fins. Most of these increase the cost of manufacturing. Recent considerations such as reducing the heat exchanger volume to reduce the volume of refrigerant and the use of thinner tubes (<5mm diameter) have not yet been assessed in terms of manufacturing costs

The relationship between the heat transfer efficiency of finned tubes to the system energy efficiency, and accordingly increased cost are shown in Figure 3.4. (Shah N, and Li T, personal communication). Both found a proportionate increase in heat transfer efficiency in relation to cost.

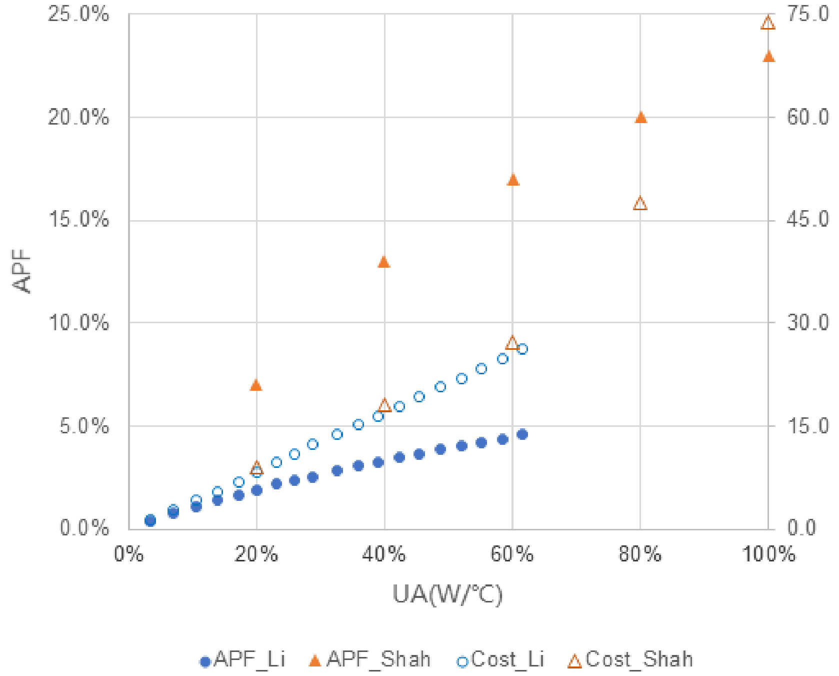


Figure 3.4: Heat exchanger cost and air conditioner efficiency changing with heat exchanger efficiency

*Micro-channel heat exchanger*s have a different mechanical structure, and approximately 40% higher heat transfer efficiency than finned tube exchangers, due to:

- Higher air side heat transferring efficiency (larger tube area facing the airflow, with tubes connected with the fins by welding or by metal forming[11], rather than by expansion);
- Less refrigerant flow resistance due to shorter and more direct tubes;
- Higher refrigerant heat transfer coefficient
- Reduced system refrigerant charge by as much as 40 %.

Micro-channel heat exchangers require more complex to develop and are difficult to use them as evaporators. In addition, they can have higher maintenance costs because they are made from aluminium and the weld points can corrode in some conditions. Nevertheless, compared to finned tube heat exchangers, micro-channel heat exchangers have similar or marginally lower (~5%) cost for the same capacity, and have higher (0-5%) efficiency.

[11] Metal forming, is the metalworking process of fashioning metal parts and objects through mechanical deformation; the workpiece is reshaped without adding or removing material, and its mass remains unchanged

3.2.4 Fans/motors

There are two main types of fan motor used in ACs - direct current (DC, efficiency 70%) and alternating current (AC, efficiency 30%). DC motors have a much higher efficiency but are almost double the cost compared to AC motors.

Air conditioner efficiency can be improved by increasing airflow rate. The air volume flow is proportional to the power of the fan Figure 3.5. There is an optimum airflow rate at which the air conditioner has highest efficiency. If the airflow is less than the optimum, increasing airflow benefits the system efficiency. However, if airflow rate is greater than the optimum then system efficiency declines Figure 3.6 due to additional power needed to overcome high-pressure loss that has a diminishing benefit to heat transfer. The cost of the fan and motor increases with increasing airflow rates in a stepwise fashion, because a single fan/motor can cover a range of airflow rates. Selecting the correct fan for cost versus efficiency varies from case to case. As can be seen, there is an optimal fan speed, above which efficiency declines and cost increases.

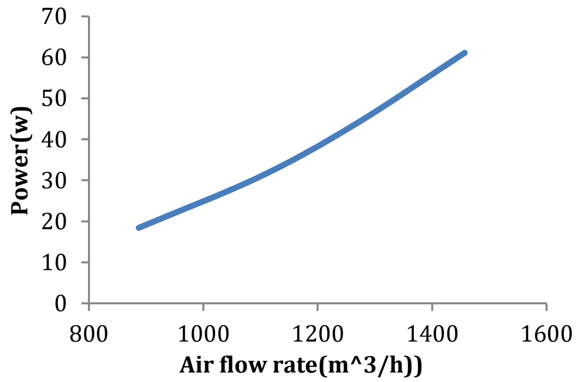


Figure 3.5: Schematic of fan power changing with airflow rate

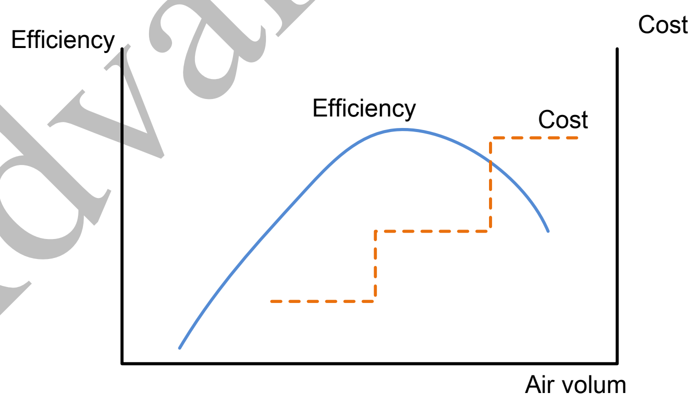


Figure 3.6: Schematic of air conditioner efficiency and motor cost changing with air flow

3.2.5 Maintenance; self-cleaning

Most ACs will have 5-10% decline in efficiency during their lifetime, mainly due to dust deposition on heat exchange surface, the more complicated the fin geometry and the more rows of tubes, then the greater the dust deposition. As a result, the resistance to airflow increases and the air flow volume decreases, which reduces the efficiency of the heat exchanger and of the AC (Figure 3.7). Therefore, regular maintenance and cleaning of the air conditioning system is essential in maintaining energy efficiency. Increasingly, new products have a self-cleaning design at an additional cost of about $20 (Task Force estimate).

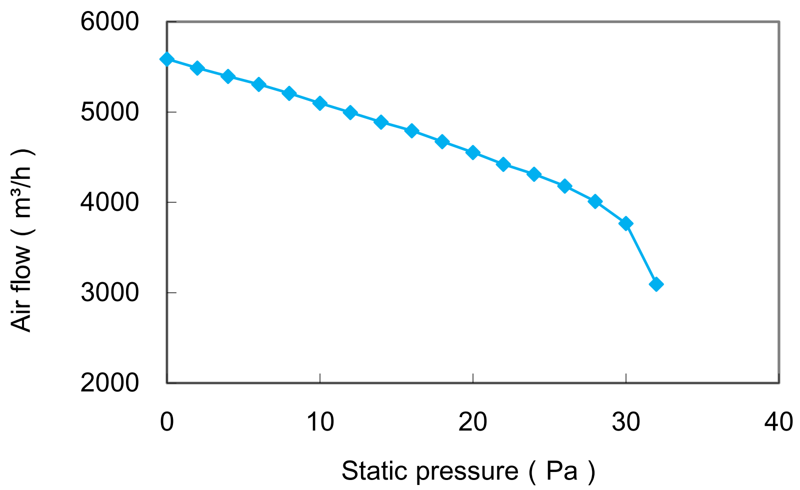


Figure 3.7: Schematic of airflow decrease changing with static pressure increase, to mimic dust build-up.

3.2.6 Retrofit technologies

Several retrofit technologies offer EE improvements compared to baseline technologies. Some of these retrofit technologies include for room air conditioning:

- Electronic, programmable, and self-learning Wi-Fi-enabled thermostat (estimated at 5% energy saving);
- Central control system (estimated at 10% energy saving); and
- Replacement of indoor and outdoor fan motors with variable speed ECM motors.

For commercial self-contained air-conditioning units, retrofit technologies include:

- Digital controllers to improve the compressor and fan controls;
- Adding doors/shields to vertical self-contained units;
- Replacing lighting with LED (reduce load and power draw); and
- Changing the thermostat set-point and reduce the glass-door heater power requirement
- Install anti-fog films on glass doors and deactivate glass door heaters (reduce load and power draw).

3.3 Costs of components for higher EE, specific to CR

As discussed in the previous sub-chapter, the energy consumption associated with a CR appliance is dictated not only by the system design and its components but also the construction of the equipment that is often unrelated to the system. Thus, there are a variety of elements that can be applied to commercial refrigeration appliances that may or may not be affected by the refrigerant type. Their cost can vary widely, depending upon the type of appliance, it's size and also its function.

Table 2.7 in chapter 2 lists all the often-considered options for improving SCCRE energy consumption; there are of course other options, but which may be applicable to non-self-contained or centralised type systems. The options have been broadly categorised according to its function, for example, improving airflow, improving fan energy, reducing heat load and so on. Of course, the effectiveness and cost of most of these options are interrelated. As noted above, the indicative additional costs are applicable to certain classes of SCCRE, but also the size of the appliance; most of these apply to a 1.2 m or 2.5 m length cabinet.

3.4 System design and optimization

3.4.1 Cost-neutral EE upgrades

EE is one of the main design features that product development engineers consider during the development of new platforms, however, there are several other important factors that impact the design including manufacturability, reliability, cost, performance, etc. An engineer will always consider cost-neutral EE upgrades, whilst potentially improving other features. Some of the relevant examples of cost-neutral or cost-reduction EE upgrades include:

- Micro-channel heat exchangers
- Improved fan designs
- Optimized air flow distribution
- Higher efficiency compressors
- Evaporator and Condenser design optimization (within certain limits)

3.4.2 Additional cost savings opportunities from EE measures

Some EE measures should be studied holistically, as they can increase or decrease costs elsewhere. For example, using brushless DC motors (electronically commutated motors, ECM) fans in commercial refrigeration units would require the use of more expensive electrical conductor (3- or 4-wires DC conductor instead of the usual 2-wires AC conductor). In contrast, a higher efficiency commercial refrigerator requires less electrical power and thus smaller electrical wire gauge and switches with a lower total installed cost.

All aluminium micro-channel heat exchangers reduce material cost, require lower refrigerant charge/cost, and because they are smaller and lighter result in reduced chassis cost, reduced cover cost, reduced packaging cost, and reduced transportation and storage costs.

3.4.3 System design and optimization case study: Sino - US CFC-Free Super-Efficient Refrigerator Project

During the phase-down of CFC refrigerants, parties were interested in providing energy efficient solutions. One of the major studies performed was the "The Sino - US CFC-Free Super-Efficient Refrigerator Project Progress Report: Prototype Design & Testing" to promote the transformation of the Chinese industry to the production of CFC-free, super-efficient domestic refrigerators (EPA, 1997). Technologies examined in that effort included:

- Non-CFC refrigerants and foam-blowing agents
- Alternate refrigeration cycles
- More efficient compressors
- Optimization of condenser and evaporator designs
- Increased insulation thickness
- Improvements to door gaskets and controls

EPA (1997) reported that the China Household Electric Appliance Research Institute (CHEARI), the Haier Group, and the University of Maryland (U. Of Md.) collaborated to build and test typical Chinese refrigerators, evaluate Chinese consumer opinion research on the marketing of ozone-friendly, energy-efficient refrigerators, and perform field testing for one year in three Chinese cities to test the performance of units under actual operating conditions. EPA (1997) concluded the following:

- Laboratory tests have demonstrated that conversion from (CFCs) to alternative refrigerants and foam-blowing agents can be achieved along with substantial energy savings as shown Table 3.3.

Table 3.3: Summary of laboratory test results

Energy Savings	Technology improvement options employed
~20%	Lorenz cycle with non-CFC refrigerant blend
~20%	Increased foam insulation (about 2 cm) to sides, back, bottom, and (1 cm) to both doors of cabinet
~40%	Increased foam insulation and improved compressor
~50%	Increased insulation, improved compressor, and Lorenz cycle with non-CFC refrigerant blend

- Chinese consumer opinion research showed that Chinese consumers care more about the quality of the product and they are willing to pay 20% more for a higher quality product which consumes 40% less energy than the models currently available.
- The optimized models showed significant higher energy savings in the field than in laboratory tests; however, noise level was a concern with the field-tested units.

3.5 Operating and Life-cycle costs

3.5.1 Methods to assess life cycle costs in policymaking (EU, DOE, Other)

As shown in the literature, market failures hinder the development of energy efficient equipment. Policymakers typically attempt to overcome such market failures by promoting more efficient equipment in order to maximize cost savings to consumers over the lifetime of the equipment. For example, the United States Department of Energy (DOE)'s Appliance and Equipment Standards Program (DOE, 2016) and the preparatory studies for the EU Ecodesign Directive (EuP, 2009; Huang et al 2018) both use "bottom-up" engineering analysis based on detailed data collection, testing and modelling of the more efficient equipment to identify the actual manufacturing cost (as opposed to the retail price) and the corresponding lifecycle cost of more efficient equipment. Similar methodologies have also been used to a more limited degree to support energy efficiency standards processes in countries such as India, China, Ghana, Mexico etc. (Shah et al., 2016; Lin and Rosenquist, 2008; Fridley et al., 2001; Buskirk et al. 2007; Sanchez et al, 2007). It should be noted that these methodologies offer a "snapshot" of the cost of efficiency improvement at any given time and will tend to provide a conservative (i.e. higher) estimate of the cost of efficiency improvement. In practice, the prices of higher efficiency equipment have been found to decline over time in various markets as higher efficiency equipment begins to be produced at scale (Taylor et al 2015; Abhyankar et al 2017; Spurlock 2013). Since the methodologies used in these standards processes are largely similar, we describe here the methodology used by the DOE in more detail.

DOE Appliance and Equipment Standards Program bottom-up engineering analysis methodology

In the United States, the establishment of federal MEPS by 1980 was first called for in the 1975 Energy Policy and Conservation Act (EPCA, Pub. L. No. 94-163). It also called for efficiency targets that are "the maximum percentage improvement" that is "technologically feasible and economically justified." Establishing these levels is done through a combination of engineering and economic analyses, including estimates of the lifecycle costs of efficiency improvement to consumers.

The main purpose of the engineering analysis is to develop a relationship between efficiency and cost of the product through methods such as product tear-down and laboratory testing. After assessing each design option, engineering models predict the efficiency impact of any one or a combination of design options on the product. This requires establishing a base case configuration or starting point, as well as the order and combination/blending of the design options to be evaluated. Table 3.4 below shows the design options in a recent DOE rulemaking for the self-contained, vertical, closed, transparent refrigerated display cabinets from the selected baseline model (AD1), along with their corresponding estimated daily energy consumption and manufacturer cost and selling price.

Table 3.4: Design options for efficiency improvement of self-contained, vertical, closed, transparent display cabinets

Design Option Level	Calculated Daily Energy Consumption, kWh/day	Manufacturer Production Cost, $	Manufacturer Selling Price, $	Design Option Added Above the Baseline
AD1	34.68	2,681.43	3,869.44	Baseline
AD2	33.59	2,689.71	3,881.19	AD1 + Permanent Split Cap. Evap. Fan Motor
AD3	28.79	2,731.63	3,940.72	AD2 + LED Lighting
AD4	27.46	2,749.21	3,965.69	AD3 + Brushless DC Evap. Fan Motor
AD5	19.41	2,864.68	4,129.66	AD4 + High-Performance Door
AD6	18.43	2,929.32	4,221.45	AD5 + Enhanced-UA Condenser Coil
AD7	18.23	2,943.28	4,241.27	AD6 + Brushless DC Cond. Fan Motor
AD8	17.31	3,033.76	4,369.75	AD7 + LED Lighting with Occupancy Sensors
AD9	17.16	3,051.55	4,395.01	AD8 + High-Eff Reciprocating Compressor
AD10	16.92	3,092.97	4,453.82	AD9 + Additional ½" Insulation
AD11	16.66	3,169.08	4,561.90	AD10 + Enhanced-UA Evaporator Coil
AD12	16.05	4,190.63	6,012.50	AD11 + Vacuum Insulated Panels

The procedure for selecting candidate standard levels begins by taking the results of the engineering analysis and the life-cycle cost analysis of the candidate design options. Candidate standard levels are determined from a range of design options that typically include the most energy efficient combination of design options; the combination of design options with the lowest life-cycle cost; and a combination of design options with a payback period of not more than three years.

One of the economic impact analyses that contributes to determining the impacts of standards on consumers is known as the life-cycle cost and payback period analysis (LCC). The inputs to the LCC include the “bottom-up” engineering analysis outputs of efficiency levels for different product classes, which are tied to manufacturer production costs (as derived with industry cooperation) and then used to generate projected product prices at each efficiency level. In the LCC, which has a five-year time horizon, the DOE determines single period consumer cost in terms of any increase in the product price and single period consumer benefit in terms of any operating cost savings from reduced product energy use. The LCC does this by adding the initial product price and operating cost data for each efficiency level as assessed over the period of a product's lifetime, starting from the effective year of the standards. This LCC along with other technical support documents are made publicly available before the final standard is established.[12]

3.5.2 Mini-split AC

Table 3.5 below shows the lifecycle cost (retail price plus installation cost plus energy cost over the lifetime of the equipment) and payback period (period of time over which the energy savings exceed the higher installation cost) to the consumer calculated using the above outlined methodology from a recent DOE[13] rulemaking document for four efficiency levels above a base level considered for mini-split air conditioning. The higher efficiency levels have higher installed costs, but lower lifetime operating costs. The data imply that at any given time ("snapshot") there is a level of efficiency above where Life Cycle Cost analysis indicates that there is a ceiling of efficiency, above which the energy savings will not payback the higher installed cost within the lifetime of the equipment. As the cost for efficient components and designs decrease over time due to increases in scale of production or learning, the cost of higher efficiency equipment decreases. As this occurs, higher levels of efficiency payback over shorter periods.

Table 3.5: Installed cost, lifecycle cost and simple payback period to the consumer for various efficiency levels for mini-split AC in the US

SEER (W/W)	Installed Cost in USD	Lifetime Operating Cost in USD	Lifecycle cost in USD	Simple payback in Years	Average Lifetime in Years
4.1 (Base)	3,714	4,758	8,472	N/A	15.3
4.3	+38	-93	-55	4.5	15.3
4.4	+105	-189	-84	4.8	15.3
4.7	+259	-295	-36	8.2	15.3
5.6	+1,105	-602	+503	16.6	15.3

3.5.3 Commercial self-contained refrigeration

For the self-contained, vertical, closed, transparent display cabinets equipment class[14]. Table 3.6 shows the lifecycle cost savings at various efficiency levels calculated using the above outlined methodology from a recent DOE rulemaking document for seven efficiency levels above the base efficiency level along with their corresponding estimated annual energy use values. The higher efficiency levels have higher installed costs, but lower lifetime operating costs. The data imply that at the technology development level during the standard setting

[12] See here for the LCC published by DOE in 2017 for Central air conditioners which include mini-split ACs: https://www.regulations.gov/contentStreamer?documentId=EERE-2014-BT-STD-0048-0100&attachmentNumber=1&contentType=excel12mebook

[13] For example, (Fridley et al 2001) used the Oak Ridge National Laboratory (ORNL) Heat Pump Design Model, Mark V, version 95d .

[14] This is one of 49 different equipment classes used by DOE to regulate commercial refrigeration equipment.

timeframe (~2013-2014) there is a ceiling of efficiency around efficiency levels 2, 3 and 4[15] at which point the energy savings will yield the maximum benefit to consumers.

Table 3.6: Lifecycle cost savings at various efficiency levels calculated using the DOE methodology. Each efficiency level corresponds to a possible design option at the time of the rulemaking.

Level	Annual Energy Use, kWh/yr	Mean Values of			Life-Cycle Cost Savings				Median Payback Period, years
		Installed Cost, 2012$	Annual Operating Cost, 2012$	LCC, 2012$	Average LCC Savings, 2012$	Customers that Experience (%)			
						Net Cost	No Impact	Net Benefit	
1	10,022	6,498	1,270	19,135	2,503	0.0	10.1	89.9	0.5
2	6,727	6,799	970	16,433	5,200	0.0	10.1	89.9	0.8
3	6,654	6,822	964	16,397	4,709	0.0	0.0	100	0.8
4	6,318	6,974	921	16,110	4,996	0.0	0.0	100	1.0
5	6,262	7,003	917	16,105	5,001	0.0	0.0	100	1.1
6	6,174	7,073	913	16,127	4,979	0.1	0.0	99.9	1.2
7	5,857	8,909	948	18,294	2,812	10.8	0.0	89.2	4.7

[15] DOE considers various efficiency levels during each rulemaking which correspond to technologies, design options and combinations of design options to improve energy efficiency that are technologically feasible at the time of setting the standard.

4 ROLE OF MARKETS IN THE AVAILABILITY OF ENERGY-EFFICIENT RAC EQUIPMENT AND LOW-GWP REFRIGERANTS

Key messages:

- Price to consumers is only loosely correlated with EE. Enterprise pricing strategies, and especially the inclusion of features that are irrelevant for EE, influence the price to a greater degree.
- EE measures deliver significant positive environmental impacts and reduces the amount of electricity that needs to be generated to deliver the same level of cooling service. National policies (MEPS, labels, pull-policies) have a significant impact on technology/product availability and price. Individual countries setting long-term targets for energy efficiency alongside the Montreal Protocol/ Kigali Amendment transition, would give their markets a clear trajectory and increase investor confidence that there will be a market for higher-efficiency products
- In addition to focusing on availability or costs, the transition towards energy efficient AC and CR can be accelerated by improving national regulations such as MEPS, market incentivisation, improving servicing capacity and training, as well as promoting financial support for local industry in A5 parties for access to IP and know-how, and capital cost conversion of manufacturing lines.
- Many A5 parties do not have local AC manufacturing and import AC equipment. They may need assistance to develop MEPS and labelling programmes to avoid importing low energy-efficiency AC equipment. For example, of African countries, currently 23 of 54 do not have MEPS. A strategy of early switching towards energy efficient low-GWP AC equipment would bring long-term economic and environmental benefits.
- The transition to lower-GWP and higher efficiency AC equipment can happen together at lower overall cost than otherwise and can be further accelerated by encouraging R&D for new solutions and approaches and through regional and international cooperation and partnerships
- Article 5 parties using HCFC technologies and with low EE or no MEPS regulations have the greatest scope to improve the EE of equipment, compared to countries with high EE MEPS regulations and already using HFCs technologies. They have the opportunity to transition directly to high efficiency/lower GWP equipment while avoiding high-GWP HFCs.
- The adoption of common standards for testing and qualification methods between markets would enable manufacturers to capitalize on scale and accelerate technology readiness. Governments setting testing and performance requirements that are not comparable with main trading partners or suppliers may disadvantage that country economically by delaying the adoption of new energy efficient technologies in that country.
- Awareness influences market and consumer choice. A good consumer communication strategy is critical to increase market penetration of more efficient products.
- International cooperation as well as regional partnerships and the development of similar metrics enable monitoring of the market, which allows an easy comparison of products on the market in different geographic regions.

- The transition can be further accelerated through regional and international cooperation and by encouraging R&D for new solutions and approaches towards low GWP and energy efficient equipment.

This chapter explores market mechanisms, dynamics, and the influence of policies on the retail price, availability of products and technologies, and presents examples from multiple geographic regions.

An essential characteristic of markets is competition among enterprises, which benefits consumers by putting pressure on enterprises to compete on prices and performance of products, including through innovation. At the same time, sector consolidation also takes place to achieve economies of scale, whereby scale of production drives down the cost. It is in this competitive context that environmental and EE policies can affect the availability and prices of products and technologies. Indeed, in markets without EE policies, such as MEPS, commercial stakeholders can continue pursuing their interests and strategically withhold or delay innovations such as improved EE that would reduce costs to consumers (Houde and Spurlock, 2016).

As discussed in Chapter 2, the transition to lower-GWP technologies and equipment is underway in some markets, and some markets have also begun transitioning to higher EE equipment and technologies. Due to the international treaty of the Montreal Protocol and to the subsequent policies that were implemented on a national level, more manufacturers have started looking for technologies using alternate refrigerants, insulation and compressors. For example, in the case of domestic refrigerators, GIZ’s collaboration with IIT Delhi and Godrej in India (GIZ, 2019) successfully introduced hydrocarbons as alternate refrigerants. The TEAP RTOC report projected that by 2020, about 75% of new refrigerator production will use HC-600a (UNEP, 2014), a transition facilitated by the smaller refrigerant charge requirements for domestic refrigerators, marginally higher cost of manufacture than that of HFC-134a and the approximately 5% higher energy efficiency of HC-600a (UNEP, 2018).

In contrast, as discussed in Chapter 2, the Montreal Protocol signal to phaseout HCFCs led manufacturers to focus their research and development efforts on non-HCFC technologies. This can be seen in a survey of almost 3000 room AC compressor models that did not identify any variable speed drive HCFC-22 compressors, suggesting that manufacturers are not investing in energy efficient HCFC-22 units (Nicholson and Booten, 2019).

As described in the examples below, the transition to lower-GWP and higher efficiency can happen together, and when well-coordinated, these transitions can occur with no increase in the prices paid by the end-user or lower overall price to consumers than otherwise.

4.1 Market forces and their effects on products

4.1.1 *Rapid evolution and growth of the RACHP market*

The market for refrigeration, air conditioning, and heat pump (RACHP) equipment is growing rapidly and is projected to grow from 3.6 billion units installed in 2016 to 9.5 billion in 2050 (Green Cooling Initiative, 2016). According to the International Energy Agency (IEA), on average 10 new air conditioners will be sold every second for the next 30 years (IEA, 2018).

In the absence of strong energy efficiency policies, countries are vulnerable to becoming the recipients of energy inefficient and obsolete RACHP equipment (Andersen et al., 2018). This phenomenon was previously observed in 1999 in Australia. The country shifted its energy efficiency programme to match the most stringent energy performance requirements mandated by Australia's trading partners after discovering that the units being imported into its market were less efficient than those allowed for sale in the country of export (CLASP, 2005). An advantage of this policy is that by relying on the standards developed by trading partners (often with larger markets), the Australian government and local manufacturers avoid the significant costs of developing regulations, and also benefit from alignment with larger markets and economies of scale.

In Ghana, prior to the adoption of energy efficiency regulations and ban on second-hand refrigerators and air-conditioners, the average domestic refrigerator consumed 1,200 kWh per year, and 80% of the market used imported appliances, mainly from Europe. The most popular refrigerator was the most inefficient on the market and almost all cooling appliances used CFCs. Following the adoption of standards and labelling policies between 2005 and 2009, over 10,000 used and inefficient refrigerators were replaced with new and more efficient ones, over 34,000 illegally imported were confiscated and destroyed, 1,500 kg of CFC was recovered, and 400 GWh of electricity saved. All these benefits occurred with no change in the price of refrigerators (Agyarko, 2018).

Similar patterns are currently observed for air conditioners (see Figure 4.1), with fixed-speed HCFC-22 units accounting for over 75% of sales in markets with no or low energy efficiency policies.

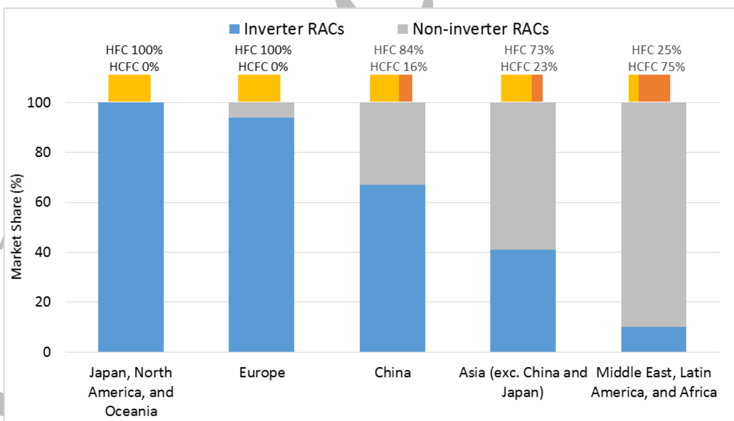


Figure 4.1 Market share of AC by compressor type and refrigerant. (Source: The Japan Refrigeration and Air Conditioning Industry Association (JRAIA) and LBNL estimates for Middle East, Latin America and Africa.)

4.1.2 Observations of prices and EE in the marketplace

As discussed in Chapter 3 and section 2.8 of the 2018 TEAP Energy Efficiency Task Force Report, (TEAP EETF 2018: UNEP, 2018), policymakers collect data and develop "bottom up" engineering analysis to identify the actual manufacturing cost (as opposed to the retail price) of efficiency improvement. These engineering "snapshots" represent the relationship between specific improvements in components, performance, and cost at a given time.

Figures 4.2, 4.3, and 4.4 are examples of such "snapshots" showing the costs of equipment/appliance versus representative energy efficiency levels (EL);

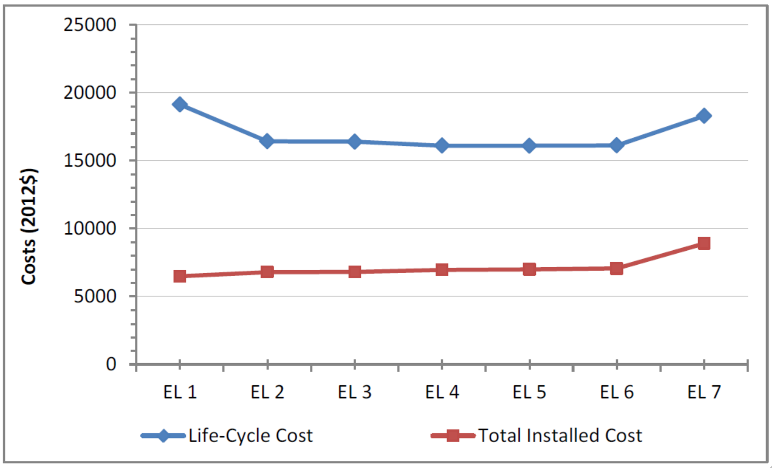


Figure 4.2. Commercial refrigerator: Life-Cycle Cost and Installed Cost Variation over Efficiency Levels (EL) for the vertical closed with transparent doors self-contained and low temperature (0°F) (VCT.SC.L) Equipment Class (US DOE, 2014).

In Figure 4.2 (above), the total installed cost for a self-contained vertical commercial low-temperature refrigeration equipment in the USA increases marginally over the baseline from energy efficiency levels (EL) 1 to 6, with a significant cost increase in EL7. However, the total lifecycle cost (LCC) is less at EL7 than EL1.

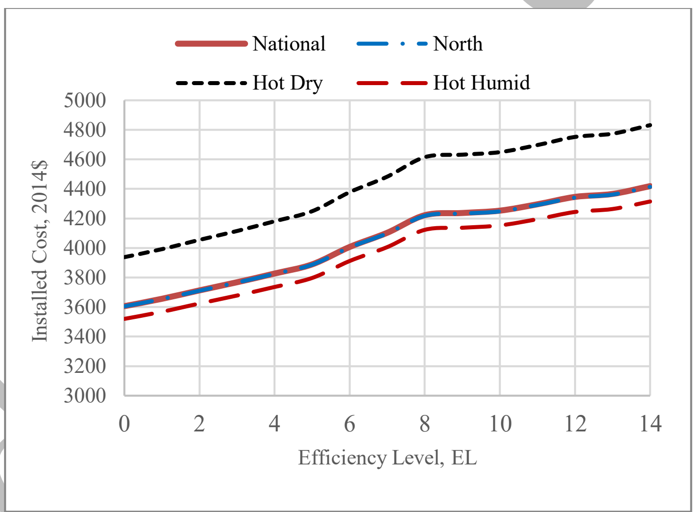


Figure 4.3. Installed Cost versus efficiency level for Split-system Central Air Conditioners in the USA at the National, North, Hot Dry and Hot Humid conditions (US DOE, 2015).

In Figure 4.3 (above) in the United States the installed cost increases as the efficiency level increases for split system central AC. However, there are regional variations (up to 10%) in installed cost due to climate impacts.

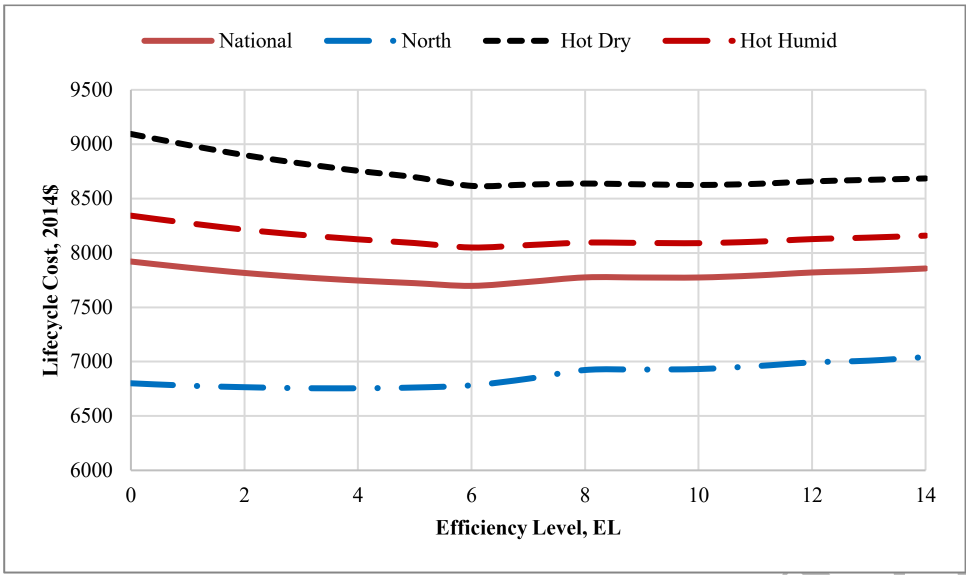


Figure 4.4. Life-Cycle Cost versus Efficiency Level for Split-system Central Air Conditioners in the USA at the National, North, Hot Dry (four states with average CDD in 2009 of over 1,700 using 18°C basis) and Hot Humid conditions (15 mid-Atlantic and Southern states with average CDD in 2009 of over 2,240 using 18°C basis) (US DOE, 2015).

Figure 4.4 (above) shows that life-cycle costs decrease with increasing efficiency level for EL1 to 6 for hotter regions while staying flat for the cooler North region for the split system central AC in the United States. The LCC in hot dry conditions is 10% greater than the national average.

However, the relationships observed between cost and EE in these "bottom up" analyses are overshadowed by other factors in the marketplace (UNEP, 2018). Retail price of products is not an adequate indicator for the costs of maintaining or enhancing EE in new equipment due to:

- Bundling of various non-energy related features with higher efficiency equipment (examples of non-energy features include mosquito repellent capability, smartphone-based control, number of different operational modes etc.),
- Variation of manufacturer's skills and know-how,
- Variation in manufacturer's pricing, marketing and branding strategies, and
- The idea that efficiency can be marketed as a "premium" feature."

Multiple studies of the retail prices and EE of appliances on many markets show that at any given time, the retail price of AC equipment is only loosely correlated with energy efficiency (Park, Shah, and Gerke, 2017; Letschert et al., 2019; Huang et al., 2018). Furthermore, projections of prices of more efficient appliances in general often overestimate the cost of the efficiency improvement when EE policies and programs are being designed (Spurlock et al., 2013; Taylor et al., 2015).

Figure 4.5 shows a "snapshot" of the relationship between the retail prices of 1-ton fixed-speed room ACs in Brazil (data collected in 2018) and 1-ton variable speed ACs in China (data collected in 2017), respectively. In Brazil, the price of a fixed-speed AC at an EER of about 3.4 (W/W) varies from about 1,100 BRL to over 1,800 BRL, i.e., over 60% variation in price for comparable equipment at the same capacity and efficiency level. In China, the price of a variable-speed AC at a SEER of about 4.5 (W/W) varies from ~3800 RMB to ~13000 RMB, for comparable equipment at the same capacity and efficiency level.

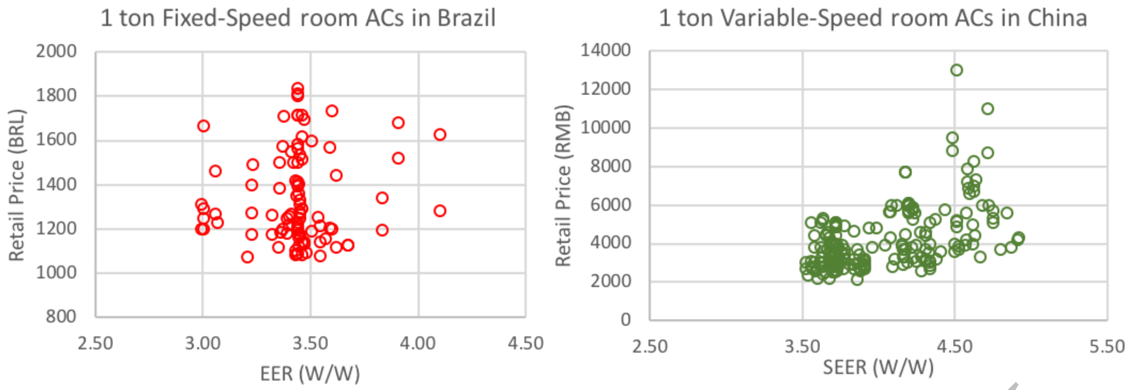


Figure 4.5: The Brazil figure (left, BRL = Brazilian Reals)) is sourced from the data from Letschert et al., (forthcoming). China (right, RMB = Chinese Yuan) data is from Park, Shah and Gerke, 2017 and the IDEA database (LBNL).

4.1.3 Market Trends over time

The above examples provide a snapshot at a given time. But these relationships evolve as the market size increases. Figure 4.6 shows a schematic illustration of observed trends in lifecycle cost, which combines retail price and cost of operation, as a function of cumulative shipments. The cost (and retail price) slowly decreases with increasing scale of production, but the introduction of energy efficiency standards, which decrease LCC accelerate this decreasing trend (Van Buskirk et al., 2014).

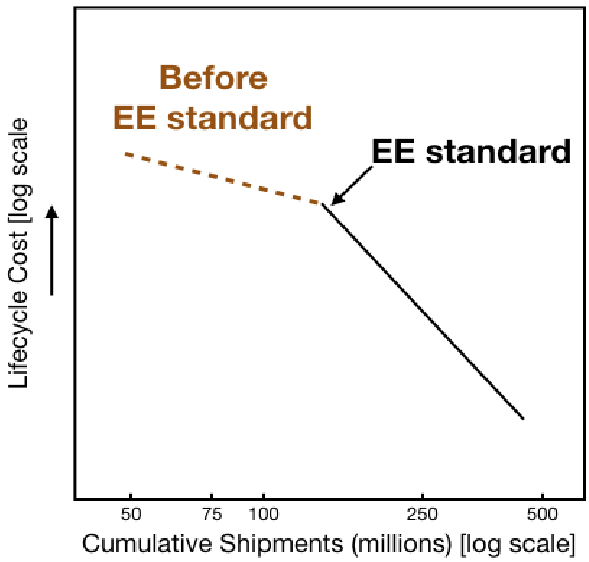


Figure 2. Schematic illustration of trends in lifecycle costs before and after a market adopts energy efficiency standards. Adapted from van Buskirk et al. (2014).

Figure 4.7, 4.8 and 4.9 show the AC efficiency relationship with evolving price in India, Japan, and South Korea (for US see TEAP 2018 EETF Report). In these figures, prices decrease over time, and efficiency increases. In these countries, there was continued effort to improve AC equipment efficiency through MEPS and other market transformation efforts.

- In India, the market-average mini-split efficiency increased from 2.4 W/W in 2006 to 3.0 W/W in 2016 while the wholesale price index (WPI) in India for mini-split units decreased by 28 points (Figure 4.7)

- In Japan, efficiency increased from 2.8 W/W to 6.0 W/W between 1990 and 2015 while the Japan's consumer price index for split-AC dropped from 100 to ~20 (Figure 4.8).
- In South Korea, the efficiency increased from 3.0 W/W (SCPF) in 1995 to ~6.5 W/W in 2015 while the Korean consumer price index dropped from 100 to ~ 40 over the same period (Figure 4.9).

The trend of decreasing prices has been concurrent with the ODS phase-out, as well as periodically increased efficiency standards. The reasons for this trend are complex, including technological innovations and manufacturing efficiencies, as well as macroeconomic factors related to globalization of manufacturing and commodity price trends. It is important to note that the adjusted equipment price did not increase following the introduction of the efficiency standards or the increase in the standards. It is also important to note that prices did not react adversely with the ban of HCFC-22 in 2010.

Empirical evidence shows a positive outcome in the previous refrigerant transitions. The same process is expected for the HFC phasedown as countries will amongst other activities, implement national policies and bans.

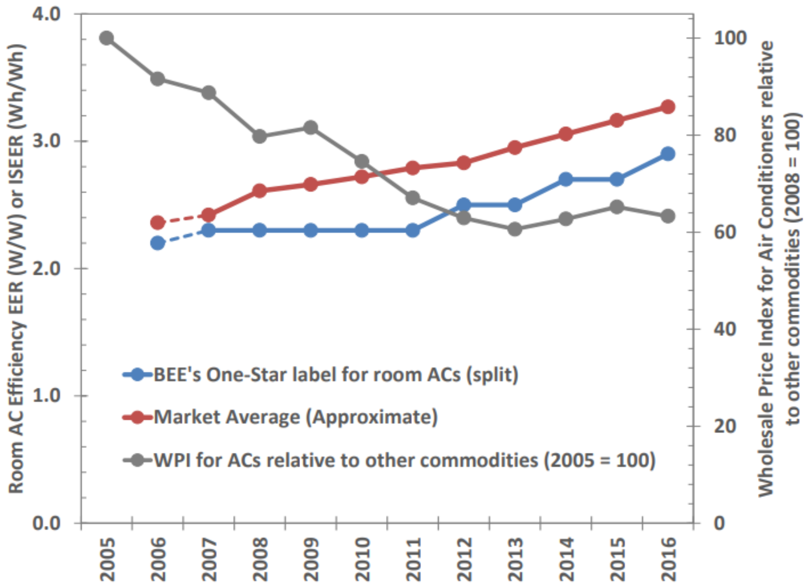


Figure 4.7. Trends in room AC efficiency improvement and decline in AC prices in India (2005-2016) (Abhyankar et al., 2017).

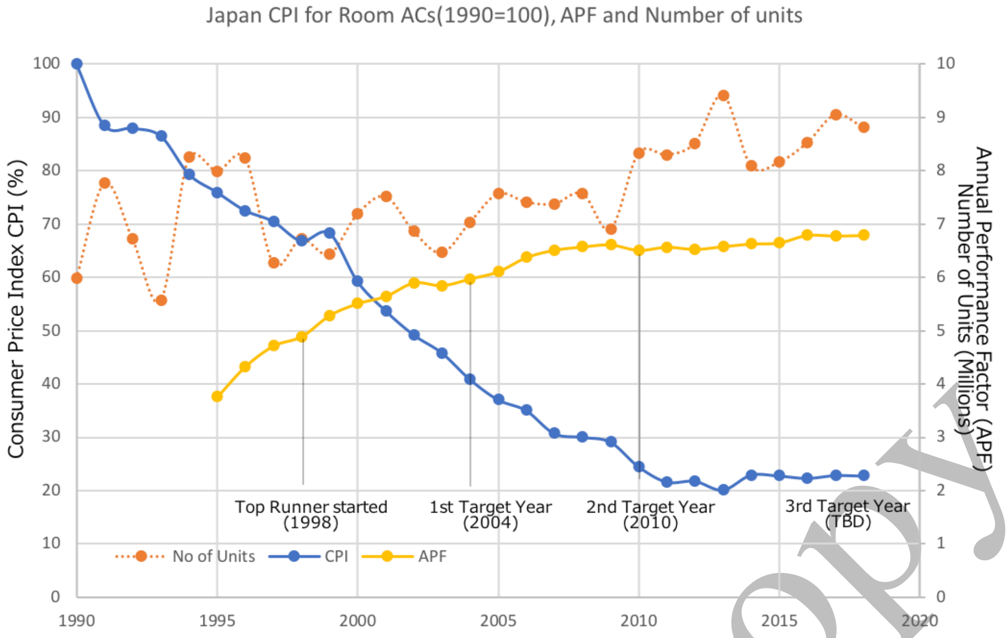


Figure 4.8. Room AC efficiency trends and price indices in Japan (Source: METI and JRAIA, 2019).

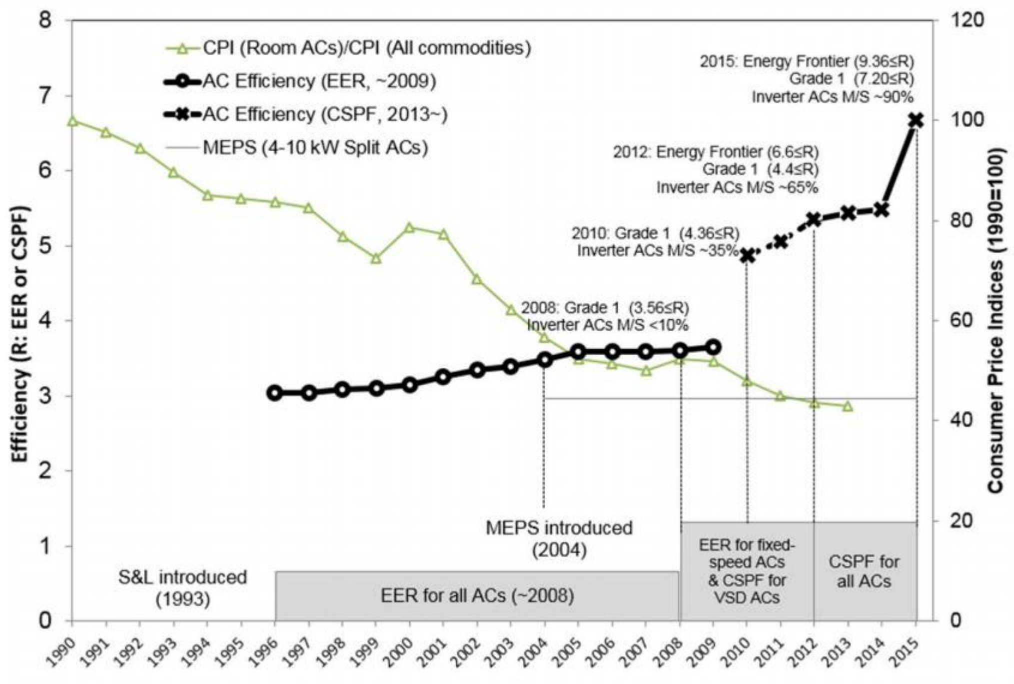


Figure 4.9. Trends in room AC efficiency and price indices in Korea (Abhyankar, et al., 2017).

4.1.4 Erosion costs

A further market mechanism affecting prices in markets with existing EE schemes are erosion costs.

In markets where there is a broad choice of products and manufacturers, EE is a selling argument to consumers, and energy efficient products carry a premium for their higher performance. In a market where energy labelling is well established, the best ranked products benefit from this premium. When a more efficient product that is in a higher label class and is the first product to populate that class, is introduced onto the market, it triggers a shift of the premium. Products that were previously in the highest class are now in the second-best class and they cannot benefit from the premium anymore. As a consequence, the premium 'jumps' one class up (Coolproducts, 2013). However, in markets where the most efficient class possible is already populated by products, manufacturers have no incentive to develop more efficient products because they cannot differentiate them within the top category, even though the new model may be more efficient than the old models. To avoid slowing down the innovation momentum, efficiency categories and labels have to regularly be rescaled as the equipment gets more efficient.

4.1.5 Importance of price transparency: a challenge in the B2B market

The market for commercial refrigeration is for the greater part a Business-to-Business (B2B) market. The market for product components is solely a B2B market. Because of the underlying nature of the B2B market, it is less transparent than the B2C (Business-to-Consumer) market: transactions are fewer but the volumes are larger and the price is often negotiable in between the buyer and seller. Good practices in communication among providers and client enterprise is key to align good services and demonstrate clearly the product market value, among other fundamental principles of the market (Wikipedia, 2019). Transparency is key for customers to demand better prices and for manufacturers to compete on price.

4.2 MEPS and other national policies

When considering energy efficiency policies and targets, including long-term targets for EE improvement at equipment level, governments consider the following criteria:

- **The baseline:** The starting point to evaluate the potential of EE improvement for refrigerant technology in an equipment, is setting the baseline of both the refrigerant technologies in use, and the equipment energy efficiency. Developing countries using HCFC technologies and with low or no MEPS regulations have the greatest scope to improve the energy efficiency of equipment, compared to countries with elevated MEPS regulations and already using HFCs technologies.
- **The performance measurement conditions:** The method of evaluation and acceptance of equipment performance implemented in a country will impact the design criteria of equipment and components. The adoption of common standards for testing and qualification methods between markets will enable manufacturers to capitalize on scale and accelerate technology readiness. Governments setting testing and performance requirements that are not comparable with main trading partners or suppliers may delay adoption of new technologies in their own country. Countries with special performance measurement and acceptance requirements due to specific local needs like HAT conditions may not have the advantage of scale in technology development, and this may delay the readiness of technology for such countries.
- **Development of building codes:** The EE of equipment is one component of system level performance, safety and environmental impact of a whole building. The reduction in cooling load in a well-designed building will impact the chosen equipment, reduce the refrigerant charge, and further reduce energy demand. (UNEP, 2018).
- **Transformative policies for Smart Cities:** RAC is an important component of smart cities. Use of IOT (smart-meters), AI, cloud networking and big data in operation of RAC technology and equipment will prove to be key driver for EE in future.

4.2.1 *The influence of EE standards and labelling on the availability of technology*

The diffusion of highly efficient technologies generally follows an "S" curve. At first, only a few early adopters will be willing to risk investing in a new, more expensive technology, so market penetration is small. After some time, when a technology has proven itself, its market penetration rates increase more quickly. Next, market penetration of the technology levels off, and only slow adopters remain resistant to adopting the new technology. Figure 4.10 illustrates how market interventions can help speed the diffusion of highly efficient technologies and can have permanent effects.

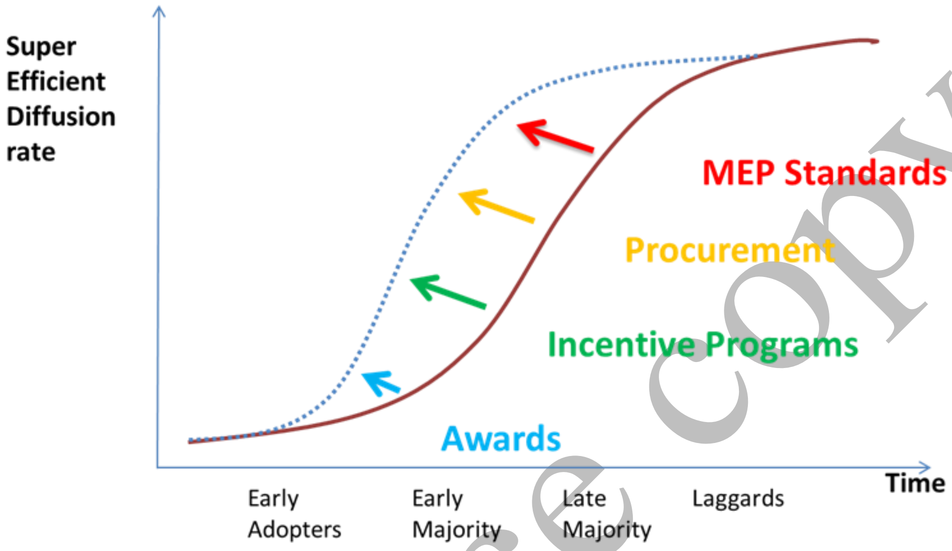


Figure 4.10: Impact of Market Interventions on Highly Efficient Technology Diffusion Rate (de la Rue du Can et al., 2014)

Among policy options, the implementation of MEPS has the greatest impact on energy savings because standards affect the majority of sales. However, significant barriers prevent MEPS from achieving cost-effectiveness, from the consumer's perspective, which is the level at which the benefits from the energy savings equal the incremental cost of efficient equipment. An analysis by SEAD of the energy-saving potential of different scenarios shows that recently implemented MEPS in SEAD economies[16] reached less than half the full potential for cost-effectiveness for ACs (Letschert et al., 2013). This indicates that in addition to increasing the stringency of MEPS in these countries to push the bottom of the market, additional market-pulling policies could complement MEPS and accelerate market transformation toward more efficient products.

As presented in Chapter 2, EE policies, such as MEPS, can affect the availability of types technologies and products. Still many countries do not have such regulation in place (Figure 4.11). The International Energy Agency (IEA) states, inter alia, that national EE standards and labelling (EE S&L) programs:

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[16] See here for the LCC published by DOE in 2017 for Central air conditioners which include mini-split ACs: https://www.regulations.gov/contentStreamer?documentId=EERE-2014.

- Bring substantial efficiency improvements for individual appliances and equipment, which can be translated to national energy savings and reductions in CO_2 emissions;
- Have improved the efficiency of appliances and equipment over the past 20 years and lowered price of products;
- Bring small long-term price changes, mainly due to the ability of appliance manufacturers to find new and cheaper ways to improve efficiency and to volume-related cost reductions;
- Have been very successful in fostering innovation, expanding existing markets and opening up new market opportunities, enhancing employment outcomes;
- In some very specific cases, the reduced energy costs resulting from EE S&L programs may be used by householders and companies to purchase additional energy services (the rebound effect);
- EE of major appliances in countries studied have increased more than three times the underlying rate of technology improvement. (IEA, 2017)

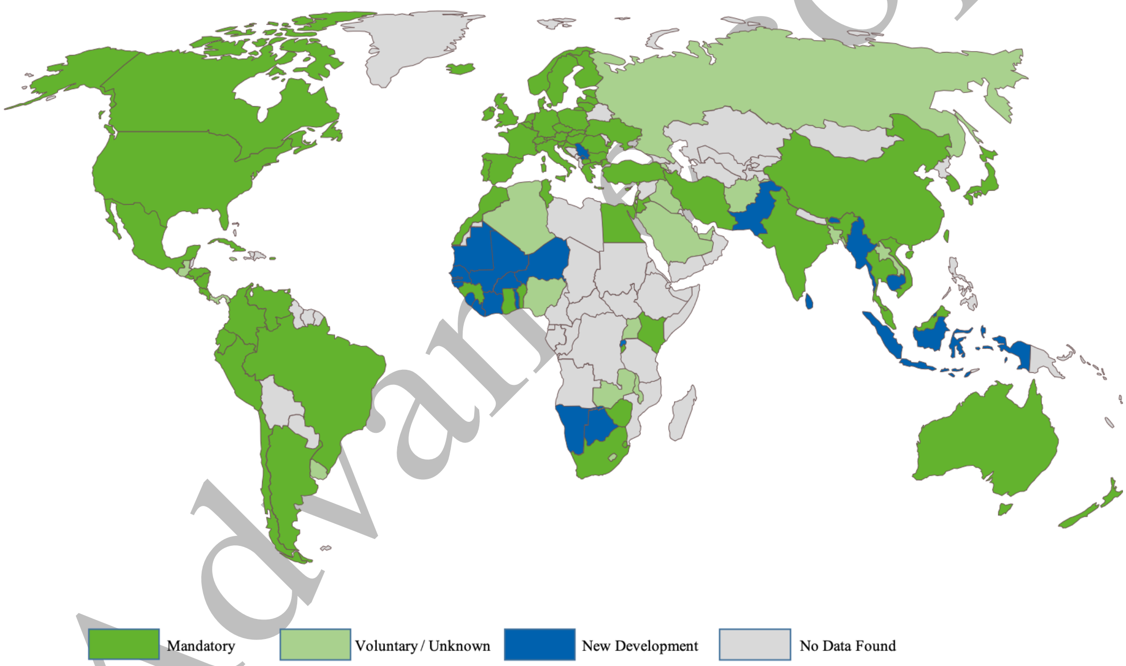

Figure 4.11. Geographies with energy performance standards for domestic air conditioners (U4E, 2019)

MEPS are not the only policy measures that can be undertaken to promote energy efficiency in the market and drive prices down. Labels, awards, buyers' clubs and incentives programs have driven market transition to higher efficiency products while prices have gone down. The TEAP Task Force Report on Issues Related to Energy Efficiency While Phasing Down HFCs (UNEP, 2018) noted that:

- MEPS can be powerful and cost-effective instruments for pushing the market towards higher-efficiency products by removing inefficient equipment from commerce;
- MEPS can work together with labels and other incentive programs, such as rebates, to "pull" the market towards more efficient technologies;

- MEPS can encourage manufacturers to improve the efficiency of their products, especially their lower-priced (lower profit margin) products sooner than they would without performance standards (Gallaher et al., 2017).

The energy saving potential from properly implemented MEPS is known to be substantial: in the European Union, for example, the combination of the MEPS (Ecodesign regulation) and the energy label is expected to save about 175 million tonnes of oil equivalent (Mtoe) annually by 2020, roughly the annual primary energy consumption of Italy. The measures also benefit consumer with an estimated saving of 456 € on their yearly household energy bill.[17]

Cost-benefit analyses must be performed before MEPS adoption, to ensure the associated regulatory measures provide economic benefits to consumers. Stakeholders consultation is required to guarantee their buy-in to the policy. Mandatory MEPS are critical to avoid dumping of appliances with low energy efficiency into a country, bringing consumers higher energy costs and an inventory of obsolete technologies in the country which will then be difficult to phase-out (Andersen et al., 2018).

Efficiency standards get customers more for their money
"Recent research suggests that more stringent energy efficiency policies result in consumers getting better quality appliances without paying more. Implementation of more stringent MEPS and product labelling in the United States affected the quality and price of refrigerators and clothes washers between 2001 and 2011. Prices for regulated clothes washers fluctuated after standards were implemented but were not higher in 2011 than in 2000. At the same time, clothes washer quality improved four-fold. If product quality is held constant, prices dropped considerably. This means that if a clothes washer first sold in 2001 was instead first sold in 2011 without any updates, it would cost about USD 450 less. Changes in product prices and quality were similar for refrigerators.
The research also showed that while room air conditioners were not regulated as strongly as other appliances studied, their quality may have benefited from standards because some innovations developed for regulated products may have been applied to room air conditioners in order to exploit economies of scale. Innovation costs were spread across more product categories, helping keep prices down across the board."
(IEA, 2017)

4.2.2 Incentives and utility obligations for EE promotion

To encourage EE, governments, utilities and other organizations offer financial incentives to make energy efficiency more accessible for today's homes and businesses. Incentive programs can take different shapes depending on the country, or municipality and can be designed in the form of rebates, loans or tax incentives. Categories of savings frequently include financial incentives for different options, such as HVAC systems, water heaters, building insulation, appliances, lighting, and other energy efficient improvements. These programs can render efficient products more affordable to the consumer who can then buy them. It also facilitates

[17] https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products

the commercialisation of new technologies and creates a demand that manufacturers can respond to[18].

Utilities, which are obliged by their governments to implement energy saving, can transform the market for energy efficient RAC equipment. Rather than setting standards for individual end-uses or industries, utility obligations require energy companies to deliver EE outcomes – typically energy savings, but in some cases carbon emission reductions or fuel poverty reductions.

However, there are examples where policies designed to promote local industry can inhibit this progressive improvement, such as the cases where domestic contents policies can sometimes interfere with the efficiency improvements of air conditioners (CLASP, 2018b).

Examples of Incentives/ Replacement programs

Replacement programmes have also proved themselves to be effective in removing inefficient appliances that are still in operation.

This sub-section presents two case studies of incentives/replacement programme, for Mexico and Brazil. The first one in Mexico is an early-replacement programme focusing on transforming the market for more efficient units, and also involving destruction of ODS. The Brazilian example shows the impact of national policy and the setting obligations for utilities to promote energy efficiency.

Case Study: National Appliance Replacement Programme in MEXICO

The Government of Mexico ran an early replacement program for air conditioning units under the Programa Nacional de Sustitución de Equipos Electrodomésticos (PNSEE), also referred as the Efficient Lighting and Appliance Project. PNSEE was designed to replace highly energy-consuming appliances, i.e., refrigerators and air conditioners that were more than 10 years old, with more energy- efficient units. This program builds on previous experience from a refrigerator replacement program implemented from 2002 to 2006 (World Bank, 2010). Launched in 2009, the target of the program was to replace 1.7 million appliances by 2012 (World Bank, 2010). They provided discount vouchers (between $25 and $70) to low-income consumers to help finance a portion of the upfront cost of acquiring new efficient appliances. The vouchers were also supplemented by providing credits to low income and higher income households (up to $470). As part of the project, old refrigerators and ACs were collected from consumers and sent to centres for dismantling and recovery of the refrigerants. The program collected nearly 1.6 million appliances of which 167’000 were air conditioners. All appliances were dismantled, the refrigerants recovered and replaced with energy efficient appliances. According to SEAD, PNSEE is one of the largest recycling programs in the world. Mexico’s PNSEE can be used as a model for other developing nations to recycle and destroy potent global-warming and ozone depleting gases in countries. (SEAD, 2015).

[18] Examples of incentive programmes can be found in the SEAD “AC Incentives Study” report, which focuses on financial incentive programmes that aim to mitigate the energy consumption attributable to the growing stock of air conditioners and describes how incentive programs can be designed to address other pressing concerns related to growing air conditioner use, such as challenges to power supply reliability resulting from increased peak demand and the global warming potential (GWP) of air conditioner refrigerants. (http://superefficient.org/publications/Lessons-Learned-From-Incentive-Programs-for-Efficient-Air-Conditioners, SEAD, 2015)

Case Study: National Refrigerator-Replacement Programme Using Utilities Obligations in Brazil

In Brazil, the Agência Nacional de Energia Elétrica (ANEEL) coordinated a plan to make energy utilities invest 1% of their revenues in energy efficiency, research and development, and energy planning. The utilities, with the regulator's oversight, public sector, academia and private sector all came together. The charge generates substantial funds to be used for energy efficiency and renewable energy investments. Frequently used programmes were refrigerator-replacement programmes. Around 30 per cent of Brazilian refrigerators are more than ten years old. Most of these old refrigerators belong to low-income households. Low-income families were prioritized and this provided additional social benefits (WEC, 2016). Between 1998 and 2016, the outcomes included: Investments US$ 2.4 billion in 4,923 projects; Energy saved 7.1 billion kWh; Peak demand reduction: 3 million kW; (Sousa, 2018). Data from United for Efficiency (United for Efficiency, U4E, 2017a) indicated that from 2008 to 2010, 45 electricity distribution companies participated in the programme, replacing more than 380,000 refrigerators.

4.2.3 Examples of market transforming initiatives

Japan's Top Runner Programme

In Japan, the energy saving standards are defined by the Act on the Rational Use of Energy etc. (abbreviation: Energy Saving Act). At the time of setting the standard, the most efficient product on the market is set as the Top Runner standard. This reference value is set as the performance target for all future products that will be put on the market in a target year. In the target year, each company must meet the Top Runner Standard calculated by the weighted average of the energy efficiency of their products. Models that have achieved the standard receive a green label. Orange labels are attached to models that have not reached the standard (Figure).

The Top Runner Program exists for 32 product categories in Japan, and domestic air conditioners are one of them. So far, the Top Runner Program does not take into account the refrigerant conversion targets of the Montreal Protocol. The Top Runner standards have been reviewed twice since the existence of the program. In the last review, the Top Runners value was set in 2005 with 2010 as the target year. Over the five years of the last programme, an energy efficiency improvement of approximately 16% has been achieved. Currently, the government is considering new target APF values for the next revision, but improvements in energy efficiency have been saturated, and alternatives are being sought (see Figure).

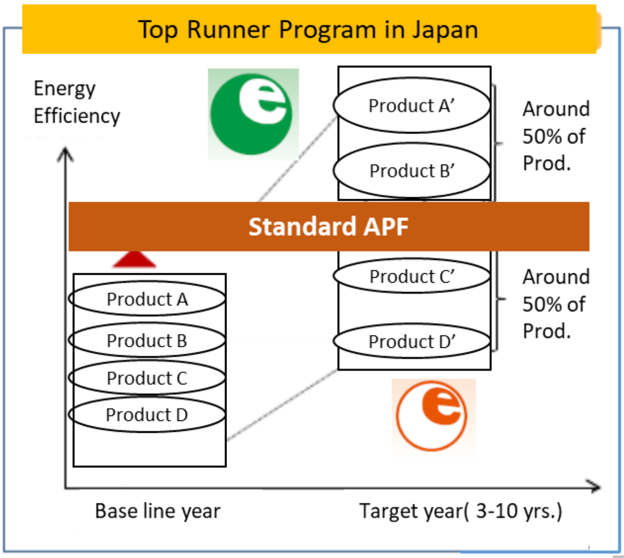

Figure 4.12: The Top Runner Program in Japan

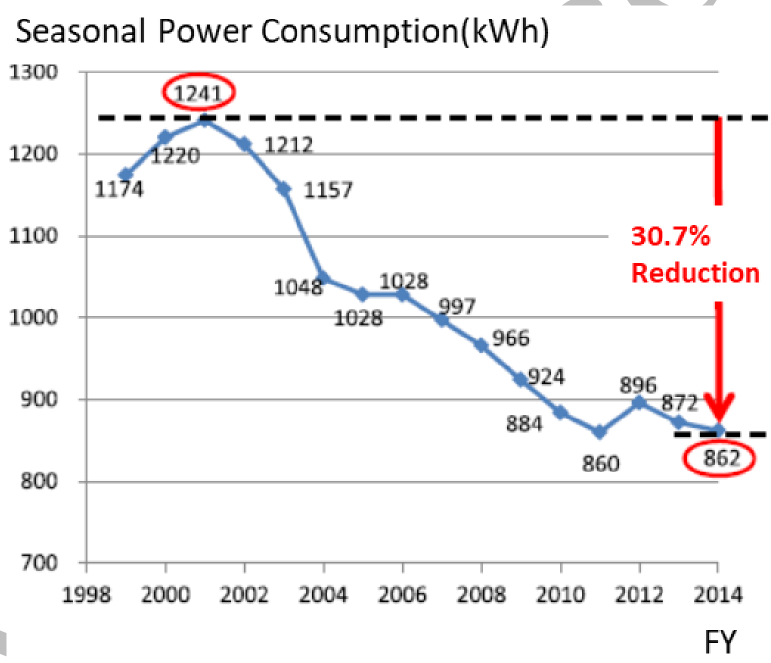

Figure 4.13: The Trend of Seasonal Power Consumption of Domestic ACs

MEPS and Indonesia

In August 2016, the Indonesian Ministry of Energy and Mineral Resources adopted a regulation for labelling and MEPS requirement for residential air conditioning. For ACs, the star rating starts from 1 star, which has a minimum of 8.53 Btu/h/W (2.5 W/W) to 4-star which has minimum of 10.41 Btu/h/W (3.0 W/W). The AC appliances testing were to be carried out appropriately by the certified agency, and the MEPS updated every 2 years.

However, in 2017, tests results of energy performance measurements showed that more than 70% of air conditioners in the market already had a 4-star rating, which meant that the regulation fixed a very low baseline for the minimum energy performance level.

Indonesian MEPS were updated by Regulation No. 57/2017 of the Minister of Energy and Mineral Resources. The updated Regulation stipulates the phasing-out of the most inefficient air conditioning split units by increasing the level of MEPS. Starting August 2018, split air conditioning units in the market must achieve a minimum of 9.01 Btu/h/W (2.64 W/W). In August 2020 the MEPS will be further strengthened to 9.96 Btu/h/W (2.92 W/W).

Having realised the importance in setting a realistic baseline to trigger a transformation in the market, Indonesia is preparing for the review MEPS for residential air conditioners aiming to achieve a total emission reduction commitment of 17% by 2030.

Figures 4.14 shows how the current label does not help differentiate in between appliances. Most products are 4-star and almost no products are 1-star. Figure 14.15 and 4.16 show how the new MEPS will impact the CO_2 emissions.

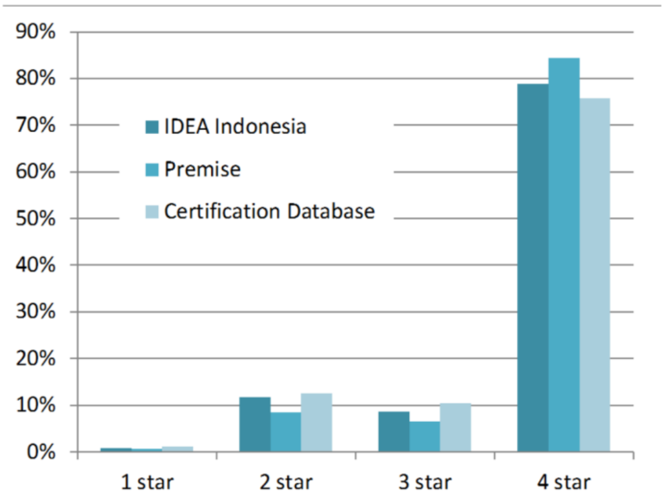

Figure 4.14: The current 4-star label does not differentiate high and low efficiency products on the market in Indonesia (Letschert et al., 2017).

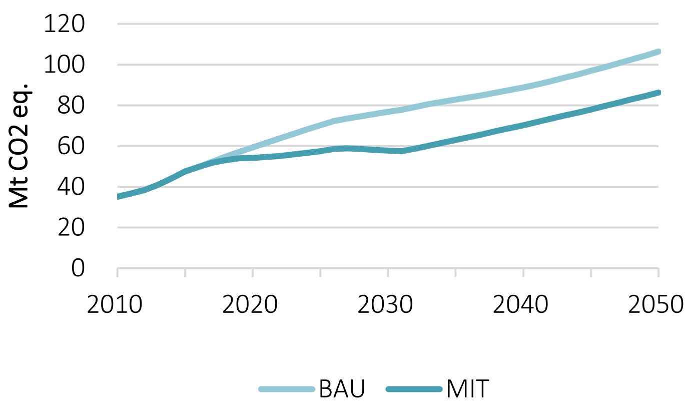

Figure 4.15: Indonesian GHG emission saving potential of over 20 Mt CO2eq by 2030 p.a. from Residential AC stock and projection in Indonesia (GIZ, 2017)

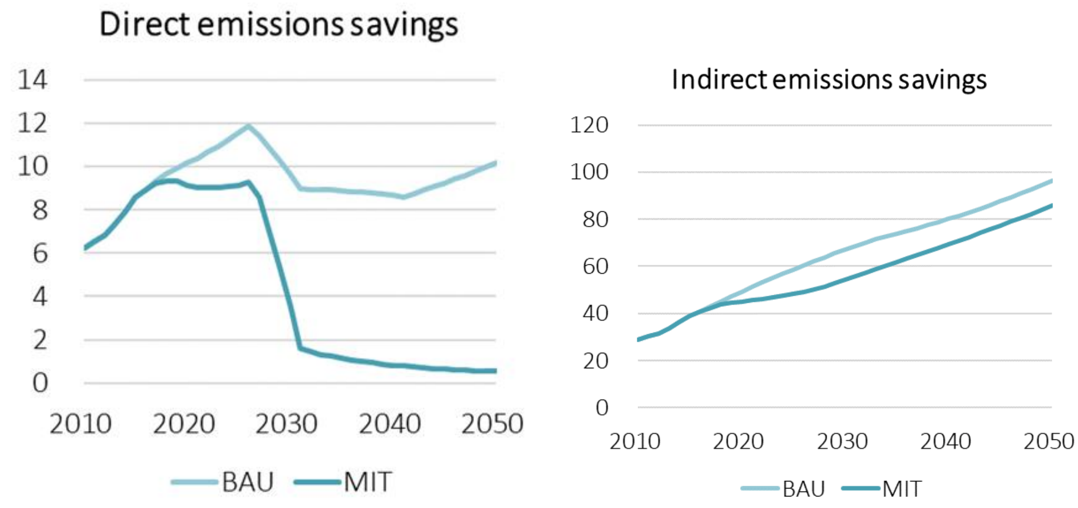

Figure 4.16: Residential AC mitigation potential from direct and indirect emissions in Indonesia for business as usual (BAU) and mitigation scenario (MIT)(GIZ, 2017)

Customer requirements: Pull-to-market of efficient commercial refrigeration

Customers for RAC have the power to pull-to-market more efficient products with low-GWP refrigerants by asking manufacturers to develop products that are in accordance with their needs. This is easier in a B2B setting where the manufacturer knows that the number of units sold will compensate for the development costs of the device. The efforts of these forward-thinking customers accelerate the time to market of high energy efficiency and low GWP refrigerant products as shown in the following examples based on information from players in the market:

- An international food & beverage company worked together with an Austrian manufacturer to develop commercial refrigeration (Ice cream freezers and Gondola freezer) that corresponded to their high energy efficiency and refrigerant requirements. The manufacturer then incorporated the technology into its own product line and streamlined it to make it accessible to all its clients.
- An international beverage company after performing an assessment of the energy consumption of their beverage coolers, decided to break exclusivity relationship with the manufacturer producing their devices to switch to a more efficient manufacturer. After having lost their client, the manufacturer developed a line of beverage coolers that was twice more efficient than their previous products within a year to try to win back their client. The manufacturer that was offering the most efficient products agreed with their client that when a they wish to develop other products with more stringent energy efficiency requirements, they would collaborate together to reach their target.

4.3 Consumer awareness of market transformation and communication

4.3.1 Awareness influences market and consumer choice

The market transition to energy efficient technologies with lower GWP refrigerants is not only determined by its costs and availability of the products but also on the marketing and communication strategy designed to create the demand amongst the consumer and trigger them to make better-informed purchase decisions.

UN Environment (2017b) identifies the lack consumer awareness as one of the main barriers in achieving a successful market transition program. Consumers have insufficient information on the most efficient technologies and their energy savings, in contrast to the MEPS that only remove the least efficient models from the market. For instance, in most African countries the low penetration of high efficiency AC using variable-speed technology was attributed to a lack of consumer awareness on the advantages of this technology (CLASP, 2018a). Standards and labelling programs are a strong tool to raise consumer awareness, but many programs only cover fixed-speed ACs or use metrics that don’t allow for recognition of the efficiency benefits of variable-speed AC technologies (CLASP, 2018a).

In the European Union, after the release of a report on market segmentation and structure for commercial refrigeration, there was an increased interest in energy efficiency among appliance buyers and manufacturers. As a result, manufacturers started to develop more efficient appliances and customers were increasingly demanding them (JRC Science, 2014).

4.3.2 Communication strategies

Awareness raising campaigns support the transitions to more energy efficient equipment while also promoting refrigerants that are compatible with the Kigali Amendment. Effective consumer awareness campaigns all rely on dissemination of information, both in a continuous manner and also at the point of purchase, when customers are at the most receptive. The difficulty is to reach the consumer at the right time with the right information. Once the purchase has been made, the consumer is locked-in with the appliance over its lifetime.

Product labelling is an effective way to educate consumers and make them aware of the impact of their product choice. Mandatory labels are more effective than voluntary labels. A voluntary label requires all stakeholders (manufacturers, retailers and consumers) to already have a minimum level of awareness so that they will participate in the scheme. Labels increase awareness by providing consumers with relevant information on high quality products. They also list financial schemes, rebates and subsidies.

4.3.3 Retailer/Installer awareness

Consumer awareness campaigns will never be able to reach and persuade an entire population and for this reason awareness raising activities must take also place on the level of retailers and installers. Buyers of RACHP products heavily rely on the advice of the salespeople or installer, who often directs the consumer towards the “appropriate” product. These intermediary players need to be educated and incentivised if they are to sell energy efficient products to consumers. If a retailer only sells efficient products, the consumer can only buy an efficient appliance. By focusing on stakeholders that make upstream decisions that will influence the availability of products onto the market, even consumers that are unaware of the benefits of buying energy efficient appliances will purchase better products without being aware of it.

4.4 Benefits of international cooperation in the refrigerant and EE transition

The success of the Montreal Protocol treaty is due to many reasons, including its ability to transform the global market of important sectors towards more environmentally friendly products in a sustainable way. It does so by developing relationships with relevant stakeholders, coming to worldwide consensus, and supporting change in developing countries through the MLF. Its Kigali Amendment will add to its successful track-record with the phase-down of HFCs, while maintaining and enhancing energy efficiency. The signing of the Kigali Amendment, followed by its entry into force on 1 January 2019, has signalled to industry, regulators and the market in general that they should begin the transition. Market penetration of new lower GWP and energy efficient technologies will be driven by national and regional policies and rely on mechanisms to push and pull the market and bring incentives and financial assistance to drive down the cost to consumers. National, regional and global policies in different market contexts will continue to drive market transformation at global scale and with different timelines taking into consideration different circumstances of countries:

- This represents an opportunity for countries to make use of what already exists, that is, countries without energy efficiency schemes can adapted and adopt minimum energy performance standards (MEPS), products labelling, and incentives schemes, which have been successful in other countries.
- Developing countries using HCFC technologies and with low EE or no MEPS regulations have the greatest scope to improve the energy efficiency of equipment, compared to countries with ambitious MEPS regulations and already using HFCs technologies. They have the opportunity to leapfrog to high efficiency/lower GWP equipment without transitioning through high GWP HFCs.
- NGOs can support the process by raising awareness, and with the implementation of MEPS.
- The adoption of common standards for testing and qualification methods between markets would enable manufacturers to capitalize on scale and accelerate technology readiness. Governments setting testing and performance requirements that are not comparable with main trading partners or suppliers may disadvantage that country economically by delaying the adoption of new energy efficient technologies in that country.
- International cooperation and the development of similar metrics enable monitoring of the market, which allows an easy comparison of products on the market in different geographic regions.

4.4.1 International cooperation driving innovation through prizes

In addition to aligning policies with trading partners to increase access to technologies and economies of scale to drive down prices, governments, manufacturers, and the broader community of researchers and inventors can benefit from innovation prizes to accelerate research, development, and deployment of high-efficiency and low-GWP technologies.

Salient to this report is the Global Cooling Prize[19], a new competition that evolved to motivate global innovation in the room air conditioning sector. The Prize seeks the development of "a climate-friendly residential cooling solution that can provide access to cooling to people around the world without warming the planet". It is an international competition calling upon international participants to develop breakthrough residential cooling technologies that has at least 5x less climate impact when compared to a baseline technology. The solution must meet a variety of climate- and resource-focused criteria, while also operating within cost and scalability constraints. The prize has the following criteria:

[19] https://globalcoolingprize.org/

- Climate Impact: the proposed technology must have at least 5 times lower lifecycle climate impact compared with the baseline unit
- Affordability: when manufactured at scale, the proposed technology should not be more than twice as expensive as the baseline technology
- Power Draw: it should not consume more than 700 W from the electrical grid
- Water: it should not consume more than 14 liters of water per day when averaged over a year (daily maximum 28 liters)
- Emissions: it should have zero onsite emissions from fossil fuel
- Refrigerant: it should use zero ODP and comply with 60335-2-40 or ISO 5149
- Scalability: it should be usable in existing homes
- Materials: limited use of high embodied carbon or rare earth materials
- Operation: it should provide 1.5 TR (5.3 kW) cooling load at standard outdoor conditions and maintain below 27°C DBT and 60% RH indoor conditions for testing period

4.5 HAT considerations

HAT conditions demand more cooling compared to normal design conditions and require special design consideration for components and systems to assure sustainable and safe operation. Cooling is a necessity for social welfare and food security. Energy consumption for cooling purposes is higher compared to normal conditions, and therefore energy efficiency has greater economic, social and environmental impact in HAT regions. Therefore, operating cooling at the highest level of energy efficiency to minimise energy consumption is a major priority for country's with HAT conditions.

4.5.1 Example from Saudi Arabia

Saudi Arabia has addressed energy efficiency in AC systems since 2007, initially with the optional energy labelling project initiated by the Saudi Standards, Metrology and Quality Organization (SASO) for residential systems. In 2011, the Saudi Energy Efficiency Center (SEEC) was formed to be the regulatory coordinating body for all energy efficiency improvement initiatives in three main sectors (Building – Industry – Transportation) by setting the objectives and then developing strategies to achieve them kingdom wide. The first MEPS for residential AC systems SASO 2663 was introduced in 2012 (Table 4.1) as result of industry collaboration with government bodies under the leadership of SEEC calling for 9.5 EER (Btu/h/W = 2.8 W/W) MEPS for residential spits at T1 condition and 6.84 EER (Btu/h/W = 2.0 W/W) at T3 condition as per ISO 5151 conditions. Two years later, MEPS were increased to 11.5 EER (Btu/h/W = 3.37 W/W) at T1 condition and 8.28 EER (Btu/h/W = 2.43 W/W) at T3 condition with mandatory transition to HFC refrigerants. Today, MEPS for residential splits have reached 11.8 EER (Btu/h/W = 3.46 W/W) at T1 condition and 8.3 EER (Btu/h/W = 2.4 W/W) at T3 condition, and MEPS regulations are covering all product types sold in the kingdom with strict implementation, all with HFC technology.

Table 4.1: Progression of MEPS in Saudi Arabia

Saudi Arabia Energy Efficiency Progression	EER (W/W) at T1	EER (W/W) at T3
2012	2.8	2.0
2014	3.37	2.43
2019	3.46	2.4

Saudi Arabia is an example of a HAT country that took steps to improve EE and has reached the currently highest possible technology limits for electrically operated systems based on full load efficiency metrics, with safety regulations based on UL/IEC 60335-2-40. For example, to increase performance to the 2012 AC energy efficiency requirements standard together with the transition to R-410A, manufacturers increased chassis size for larger R-410A compressors to accommodate the higher discharge temperature, resulting in higher prices for these models. To achieve 12 EER (Btu/h/W = 3.5 W/W) at T1, manufacturers are using microchannel heat exchangers (due to limitation on increasing EER without microchannel) and oversizing and cost considerations. The manufacturers were given confidence to invest by the strong enforcement of compliance. This led to healthy competition for availability of EE products at competitive prices (SEEC, 2018). It is to be noted that Saudi Arabia uses EER rather than SEER as its metric to evaluate energy efficiency performance.

Commercial refrigeration is under consideration as an opportunity to adopt lower GWP refrigerants with an established technology suitable for all ambient conditions (Ammonia CO_2 cascade systems).

5 Discussion

The report has conducted a thorough review of the availability of technologies and components needed for the energy efficiency and HFC phase-down transition and included where possible the best estimate of costs based on existing information. The assessment considered HAT conditions as well. Established commercial refrigeration technology is suitable for all ambient conditions and efficient air conditioning technology is also available in HAT countries.

The costs data developed in chapter 3 are estimates and actual values may be different in the actual transition. As shown in chapter 4, the influence of market mechanisms and national policies play a large role on the availability and costs of equipment and components and is considered as the main levers for the simultaneous energy efficiency and refrigerant transition. Once the proper policies are put in place, manufacturers will receive the positive signals to further invest in their R&D and this expansion will further change the costs associated with the refrigerant and energy efficiency transition through the market mechanisms illustrated above.

EE gains are possible for both commercial refrigeration and air conditioners. Many EE gains can be achieved by influencing the built of other components that are not related to the choice of refrigerant but rather on the build of the equipment (i.e. glass doors on commercial refrigerators).

This report highlights the interplay between policies and markets with the availability and cost of low-global-warming-potential technologies and equipment that maintain or enhance energy efficiency. The transition to lower-GWP and higher efficiency AC equipment can happen together at lower overall cost to manufacturers and consumers than would be the case absent coordination. Strategic planning, such as demonstrated by India with the India Cooling Action Plan finalized in March 2019, is expected to facilitate and accelerate such coordinated transition by identifying goals and priorities and defining the necessary approaches, policies, and timetables for delivering on them. Such transitions are also expected to benefit from support for R&D and international and regional cooperation.

In implementing national policies that follow the requirements of the Kigali Amendment while maintaining or enhancing energy efficiency, countries can rely on existing policies and standards in adopting their own regulation. Because a lot of the equipment is widely available, they do not need to create new product evaluations, bottom-up engineering analyses and life cycle cost modelling. International cooperation is beneficial, and policies and regulation can be set up at lower costs than otherwise. Furthermore, MEPS based on similar measurement methods and metrics allow for an easier comparison.

Individual countries could establish policies and minimum performance standards in a timely manner in order to avoid the dumping of inefficient products that cannot be sold elsewhere because of the MEPS in force in other countries. In a country receiving inefficient RAC products, individual consumers will pay higher electricity bills, and the country will need to meet the long-term increase in power demand.

REFERENCES

Abhyankar, Nikit, Nihar Shah, Won Young Park, and A. A. Phadke. *Accelerating energy efficiency improvements in room air conditioners in India: Potential, costs-benefits, and policies*. (2017). http://eta-publications.lbl.gov/sites/default/files/lbnl-1005798.pdf

Agyarko, K. (2018). *MEPS & Energy Labels for Cooling Equipment – An Importing Country Perspective. Workshop on Energy Efficiency Opportunities While Phasing Down HFCs*, Vienna, 9-10 July 2018. http://conf.montreal-protocol.org/meeting/workshops/energy-efficiency/presentations/SectionV/Session%20V_1%20Kofi%20Agyarko.pptx

Andersen SO, Ferris R, Picolotti R, Zaelke D, Carvalho S, and Gonzalez M, 2018. *Defining the Legal and Policy Framework to Stop the Dumping of Environmentally Harmful Products*, Duke Environmental Law & Policy Forum 1-48. Available at: https://scholarship.law.duke.edu/delpf/vol29/iss1/1

ASHRAE, 2019. Webinar presentation on "*Unitary HVAC Market Evolution and Global Trends*" presented by S Kim.

BEE India Bureau of Energy Efficiency India https://www.beeindia.in/iseer-eer-bee-cop-star-ratings-ac/

Bhasin, S., Sridhar, L., Chaturvedi, V. (2017). Developing an Ecosystem to Phase Out HFCs in India; Establishing a Research and Development Platform. Council on Energy, Environment and Water (CEEW). http://www.ceew.in/sites/default/files/CEEW-Developing-an-Ecosystem-to-Phase-Out-HFCs-in-India-3Oct17.pdf

China National Standards (2013). GB 21455-2013: The minimum allowable values of the energy efficiency and energy efficiency grades for variable speed room air conditioners http://c.gb688.cn/bzgk/gb/showGb?type=download&hcno=3A8FF0FAFE08A1920B7F3D41E5A9E5D9.

CLASP (2005) Energy-Efficiency Labels and Standards: A Guidebook for Appliances, Equipment, and Lighting, 2nd Edition.

CLASP (2014). Commercial refrigeration equipment: mapping and benchmarking.Waide, P., van der Sluis, S., Michineau, T. Waide Strategic Efficiency Ltd, Saint Trofee and Cemafroid.

CLASP, (2018a). Africa Air Conditioner Market Scoping Study. Available at: https://clasp.ngo/publications/scoping-study-of-african-air-conditioner-markets. Accessed 22 April 2019.

CLASP, (2018b). Technical and Economic Feasibility Study for a High Efficiency Compressor Market in Brazil. Available at: https://clasp.ngo/publications/technical-and-economic-feasibility-study-for-a-high-efficiency-compressor-market-in-brazil

CLASP, 2019. The Role of Trade Policy and Energy Efficiency Policy to Promote Highly Efficient Air Conditioner Markets. Available at: https://clasp.ngo/publications/the-role-of-trade-policy-and-energy-efficiency-policy-to-promote-highly-efficient-air-conditioner-markets

Clodic, D. and Zoughaib, A., (2000).Technical and Economical Evaluation of Vacuum Insulated Panels for A European Freezer International Refrigeration and Air Conditioning, Purdue, USA.

Coolproducts, 2013. "Fine-tuning the Ecodesign engine: Improving on the Least Life Cycle Cost criterion for a doubling of energy savings". Available at: https://www.coolproducts.eu/policy/fine-tuning-report. Accessed 23 April 2019.

DOE (2017). Energy Conservation Program: Energy Conservation Standards for Residential Central Air Conditioners and Heat Pumps CFR Vol 82, https://www.govinfo.gov/content/pkg/FR-2017-01-06/pdf/2016-29992.pdf. Accessed May 18th 2019.

de la Rue du Can, S., G. Leventis, A. Phadke, A. Gopal. 2014. "Design of Incentive Programs for Accelerating Penetration of Energy-Efficient Appliances." *Energy Policy,* v. 72, September, pp. 56–66

Dreyfus, G. Andersen, S. O., Kleymayer, A. M., Anderson, S.(2018). Primer on Energy Efficiency: http://www.igsd.org/wp-content/uploads/2018/01/EEPrimerDraft.pdf

Ecodesign for Commercial Refrigeration. Preparatory study update, Final report 2014. European Commission, Joint Research Centre, Institute for Prospective Technological Studies (IPTS)

ECREE (2015). Development of the Minimum Energy Performance Standards (MEPS) of Air-conditioners and Refrigerators in ECOWAS Region. http://www.ecreee.org/procurement/development-minimum-energy-performance-standards-meps-air-conditioners-and-refrigerators

European Commission (2019). Sustainability and circular economy: Ecodesign. http://ec.europa.eu/growth/industry/sustainability/ecodesign_en

European Commission (2019b). About the energy label and ecodesign. https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/about_en

Energy Conservation Program: Energy Conservation Standards for Residential Central Air Conditioners and Heat Pumps CFR Vol 82 2017: https://www.govinfo.gov/content/pkg/FR-2017-01-06/pdf/2016-29992.pdf

EPA 1997, "The Sino - US CFC-Free Super-Efficient Refrigerator Project Progress Report: Prototype Design & Testing", http://eta-publications.lbl.gov/sites/default/files/epa-ee-ac-project1997.pdf

European Commission (2011). Commission Delegated Regulation (EU) No 626/2011 of 4 May 2011 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of air conditioners. https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32011R0626

European Commission (2019). Ecodesign. http://ec.europa.eu/growth/industry/sustainability/ecodesign_en

Foster A, E. Hammond, T. Brown, G. Maidment, J. Evans, 2018. Technological Options for Retail Refrigeration; International Institute of Refrigeration.

Foster Miller, Southern California Edison RTTC, Oak Ridge National Laboratory (2004). Investigation of Energy-Efficient Supermarket Display Cases, ORNL/TM-2004/292.

Fridley DG, Rosenquist G, Lin J, Li A, Xin D, Cheng J, 2001. "Technical and Economic Analysis of Energy Efficiency of Chinese Room Air Conditioners". Lawrence Berkeley National Laboratory. Available at: https://cloudfront.escholarship.org/dist/prd/content/qt9cw020f8/qt9cw020f8.pdf?t=lnqwo1.

Gallaher M, et al., 2017. "Benefit-Cost Evaluation of U.S. Department of Energy Investment in HVAC, Water Heating, and Appliance Technologies". Available at: https://energy.gov/sites/prod/files/2017/09/f36/DOE-EERE-BTO-HVAC_Water

Heating_Appliances 2017 Impact Evaluation Final.pdf Green Cooling Initiative, 2016. Country data and projections available at: https://www.green-cooling-initiative.org/country-data/. Accessed 23 April 2019.

Green cooling initiative (2019a). Country data - Total emissions of cooling sector. https://www.green-cooling-initiative.org/country-data/. Accessed May18th 2018.

Green cooling initiative (2019b). Manufacturing activity of multi-national UAC manufacturers. https://www.green-cooling-initiative.org/refrigeration-sectors/unitary-air-conditioning/market-overview/market-overview-sankey/. Accessed May 18th 2019.

GIZ (2017). "Refrigeration and Air Conditioning Greenhouse Gas Inventory for Indonesia". Accessed May 10th 2019. http://ebtke.esdm.go.id/post/2017/11/07/1811/refrigeration.and.air.conditioning.greenhouse.gas.inventory.for.indonesia

GIZ. (2019). Conversion of the production of split and window-type air conditioners to hydrocarbon technology. https://www.giz.de/en/worldwide/16863.html. Accessed May 18th, 2019.

Gulf Standard Organization (2016). GSO 2530:2016: Energy Labelling And Minimum Energy Performance Requirements For Air-Conditioners. https://www.gso.org.sa/store/gso/standards/GSO:738037/GSO%202530:2016?lang=en. Accessed May 18th 2019.

Huang B, Skov Hansen PM, Viegand J, Riviere P, Asloune H, et al., 2018. "Air conditioners and comfort fans, Review of Regulation 206/2012 and 626/2011 Final report". (Research Report) European Commission, DG Energy.

Houde, S., Spurlock, M. Minimum Energy Efficiency Standards for Appliances: Old and New Economic Rationales. Berkeley, CA: Lawrence Berkeley National Lab, 2016. 1006327.

Intertek Evolving Regulations http://www.intertek.com/blog/2015-02-10-cre/

IEA 4E (2012). Benchmarking report for Retail display cabinets. https://mappingandbenchmarking.iea-4e.org/matrix

IEA (2017). International Energy Agency -- Energy Efficiency 2017, OECD/IEA, 2017-Drivers of Energy Efficiency Gains. www.iea.org

IEA, 2018. "The Future of Cooling: Opportunities for energy-efficient air conditioning". Available at: https://webstore.iea.org/the-future-of-cooling

Industrial Efficiency Technology Database. Energy Conservation Law of Japan (ECL). http://ietd.iipnetwork.org/content/energy-conservation-law-japan. Accessed May 18th 2019.

Investigation of Energy-Efficient Supermarket Display Cases, ORNL/TM-2004/292. Foster Miller/ Southern California Edison RTTC / Oak Ridge National Laboratory. December, 2004.

JRAIA (2018). World Air Conditioner Demand by Region. https://www.jraia.or.jp/english/World_AC_Demand.pdf. Accessed May 18th 2019.

JRC Science. (2014). *Ecodesign for Commercial Refrigeration - Final report.* https://doi.org/10.2791/11459

KEMCO. Korea Energy Standards and Labeling – Market Transformation. Korea Energy Management Corporation http://www.kemco.or.kr/nd_file/kemco_eng/KoreaEnergyStandards&Labeling.pdf

Letschert, V. S de la Rue du Can, M. McNeil, P. Kalavase, A. Hua Fan, G. Dreyfus. (2013). Energy-Efficiency Appliance Standards: Where do we stand, how far can we go and how do we get there? An analysis across several economies. Berkeley CA: Lawrence Berkeley National Laboratory Report LBNL-6294E

Letschert V, et al. (2017) Baseline Evaluation and Policy Implications for Air Conditioners in Indonesia. 9th EEDAL

Letschert Virginie, Nihan Karali, Won Young Park, Nihar Shah, Gilberto Januzzi, Fernando Costa, Roberto Lamberts, Kamyla Borges, Suely Carvalho. 2019. The Manufacturer Economics and National Benefits of Cooling Efficiency for Air Conditioners in Brazil, ECEEE summer study proceedings, 2019.

Lin J and Rosenquist G. "Stay cool with less work: China's new energy-efficiency standards for air conditioners", *Energy Policy* 2008;36.3; 1090-1095. doi: https://doi.org/10.1016/j.enpol.2007.11.019.

Nicholson, S. and C. Booten. 2019. Mapping the Supply Chain for Room Air Conditioning Compressors. Clean Energy Manufacturing Analysis Center (CEMAC). NREL/TP-6A20-73206. Golden, CO: National Renewable Energy Laboratory."

Park WY, Shah N, and Gerke BF. (2017). "Assessment of commercially available energy-efficient room air conditioners including models with low global warming potential (GWP) refrigerants". Berkeley, CA: Lawrence Berkeley National Lab. 2001047. Available at: http://eta-publications.lbl.gov/sites/default/files/assessment_of_racs_lbnl-_2001047.pdf. Accessed 23 April 2019.

Rauss, D., Mitchell, S., Faramarzi, R. (2008) Cool Retrofit Solutions in Refrigerated Display Cases. Proc. ACEEE Summer Study on Energy Efficiency in Buildings.

Sanchez, I., Pulido, H., McNeil, M.A., Turiel, I. and della Cava, M., 2007. Assessment of the Impacts of Standards and Labeling Programs in Mexico (four products).

SEAD, 2015. http://superefficient.org/publications/Lessons-Learned-From-Incentive-Programs-for-Efficient-Air-Conditioners

SEEC, 2018. Presentation at COP24. Available at: https://ksa-climate.com/wp-content/uploads/2018/12/Raed-Al-Schneiber_SEEC.pdf. Accessed 22 April 2019.

Sousa S, 2018. General Coordinator for Energy Efficiency, Ministry of Mines and Energy, "Energy Efficiency Actions of the Federal Government for the Building Sector" presented at the Brazil-UK Energy in Buildings Summit, 25th April 2018, São Paulo, SP

Spurlock, C. Anna, Hung-Chia Yang, and Larry Dale. *Energy Efficiency and Minimum Standards: a Market Analysis of Recent Changes in Appliance Energy Efficiency Standards in the United States*. No. LBNL-6353E. Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States), 2013. https://www.osti.gov/servlets/purl/1165985

Taylor, Margaret, C. Anna Spurlock, and Hung-Chia Yang. Confronting Regulatory Cost and Quality Expectations: An Exploration of Technical Change in Minimum Efficiency Performance Standards. 2015. LBNL-1000576. http://eta-publications.lbl.gov/sites/default/files/lbnl-1000576.pdf

de la Rue du Can, S., G. Leventis, A. Phadke, A. Gopal. 2014. "Design of Incentive Programs for Accelerating Penetration of Energy-Efficient Appliances." *Energy Policy*, v. 72, September, pp. 56–66.

UN Environment, Global Environment Facility, & United for Efficiency, 2017a. "Accelerating the global adoption of energy-efficient and climate-friendly air conditioners". Accessible at: https://united4efficiency.org/resources/accelerating-global-adoption-energy-efficient-climate-friendly-refrigerators/

UN Environment, Global Environment Facility, & United for Efficiency, 2017b. "Accelerating the global adoption of energy-efficient and climate-friendly air conditioners". Accessible at: https://united4efficiency.org/resources/accelerating-global-adoption-energy-efficient-air-conditioners/

UNEP (2014). Assessment Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC). Available at: http://ozone.unep.org/sites/ozone/files/documents/RTOC-Assessment-Report-2014.pdf. Accessed 22 April 2019.

UNEP (2018). Assessment report of the Refrigeration and Air conditioning Technical Options Committee (RTOC).

UNEP (2018). September 2018 TEAP Report, Volume 5: Decision XXIX/10 Task Force Report on issues related to energy efficiency while phasing down hydrofluorocarbons (updated final report). Available at: http://conf.montreal-protocol.org/meeting/mop/mop30/presession/Background-Documents/TEAP_DecisionXXIX-10_Task_Force_EE_September2018.pdf. Accessed 17 October 2018.

University of Birmingham (2018). A cool world: Defining the energy conundrum of cooling for all. https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/2018-clean-cold-report.pdf. Accessed May 18th 2019.

US DOE. (2014)., Technical support document: energy efficiency program for consumer products and commercial and industrial equipment commercial refrigeration equipment. https://www.regulations.gov/contentStreamer?documentId=EERE-2010-BT-STD-0003-0102&contentType=pdf, pp. 8-33.

US DOE. (2015). Technical support document: energy efficiency program for consumer products: Residential Central Air Conditioners and Heat Pumps. https://www.regulations.gov/contentStreamer?documentId=EERE-2014-BT-STD-0048-0029&attachmentNumber=1&contentType=pdf, chapter 8

Van Buskirk, Robert, Essel Ben Hagan, Alfred Ofosu Ahenkorah, and Michael A. McNeil (2007). "Refrigerator efficiency in Ghana: Tailoring an appliance market transformation program design for Africa." *Energy policy* 35, no. 4: 2401-2411.

Van Buskirk, R., Kanter, C., Gerke, B., & Chu, S. (2014). A retrospective investigation of energy efficiency standards: Policies may have accelerated long term declines in appliance costs. Environmental Research Letters, 9, 114010. doi:10.1088/1748-9326/9/11/114010.

Wikipedia, (2019). Business-to-business. https://en.wikipedia.org/wiki/Business-to-business-. Accessed May 18th, 2019.

ANNEX 1

Market aspects

In this section, the Task Force has summarised data from a range of sources, and from its collected experience. We have summarised miscellaneous country level information on policies, markets, and EE programmes which is publicly available up to May 2019:

Products/manufacturers presence in different markets.

Residential air conditioning has the highest predicted growth and emissions of all the refrigeration and air conditioning sectors (Green cooling initiative, 2019a. University of Birmingham, 2018).

China plays an important role in this sub-sector as it has the highest demand for AC units (JRAIA, 2018) as well as being the biggest producer (Green cooling initiative, 2019b). China has been in the process of updating its MEPS for residential air conditioning. China is in the process of updating its MEPS for residential ACs and subsidized energy efficient ACs, leading to improving energy efficiency in the country's AC stock. China is able to provide way more than half of the world's RAC demand and a few key Chinese producers could become highly influential in changing the RAC market. All leading Chinese suppliers are for example already able to produce highly energy efficient equipment with HC-290 as refrigerant. Nevertheless, in China, there are still significant numbers (circa 40 million) of level 3 fixed speed room ACs sold in 2018 last year (ChinaIOL).

The predicted rising demand is also related to many developing countries being far from reaching their full saturation with RAC. Apart from few countries, such as Thailand, there is little production in these countries, which therefore have to rely on imports. More and more developing countries have recently introduced MEPS or are in the process of introducing MEPS and labels in order to protect themselves against being the dumping ground for energy-intensive units. More stringent MEPS that are at least as demanding as the Chinese standards will drive the development towards more energy efficient appliances in the long term. Higher MEPS could be a chance for RAC manufacturers in Thailand to gain a competitive advantage in the market, as they are already producing for the Japanese market with its very high energy-efficiency requirements. RAC demand in India will grow strongly in the future. Energy demand from this RAC will put an additional burden on the already tight electricity supply situations. India will greatly benefit in the future by further heightening MEPS targets. As India will be the next biggest emerging market outside of China, Indian companies will play a much more important role in the future. Energy-efficient split AC with inverter technology and low GWP are not as established yet in Indian companies as they are in Chinese companies, but their introduction could lead to very high emission savings in the future.

Mandatory MEPS for the majority of residential AC consuming countries could lead to a shift to higher energy efficiency globally. There are now good practice MEPS examples from developing countries such as Ghana and India. Raising public awareness about MEPS is important for the successful implication and this could be supported by NGOs. The introduction of MEPS will significantly increase if there is broad stakeholder support. NGOs can also support countries with the implementations of MEPS. China has shown that subsidies for energy efficient models can be very successful to catalyze the introduction of highly energy efficient appliances until the production has reached sufficiently high economies of scale. Often, for the economy the costs of such catalyzing introduction programme will be quickly paid back as higher investments in electricity generation, especially for additional costly peak power plants can be avoided. The MLF can accelerate the introduction of energy efficient technologies by only financing Asian manufacturer dominate the world stage in RAC. Chinese manufacturers mainly produce residential AC within their own country whereas Japanese and South Korean companies have most of their production outsourced to other Asian countries. Chinese and Korean manufacturers have started producing in Africa.

In the Southern Hemisphere AC market. Australia showed favourable growth and acted as a driving force in 2017. The Brazilian market has been showing signs of recovery recently. In Africa, several markets have growth potential for AC.

Algeria: The Algerian government banned imports of RAC in 2018 in order to nurture local production and local brands. Accordingly, local brands have been expanding their market share, especially for wall-mounted air conditioners and several foreign manufacturers have set-up RAC production bases in Algeria. The Algerian government introduced an energy law that impose a tax from 5 to 30% on air conditioners according to their energy efficiency. High efficiency air conditioners using inverter technology were expected to expand their share in the market. However, the law was repealed under pressure from manufacturers could not meet the energy standards. One manufacturer benefited from an MLF grant to convert their production line to HFC-32. The manufacturer planned to launch the higher efficiency inverter line with HFC-32 but had to put these plans on hold when the proposed tax law was repealed. The manufacturer is going back to fixed speed units.

In **Australia**, almost all air conditioners excluding window type RACs are inverter units. In 2017, both room air conditioners (RACs) and packaged air conditioners (PACs) recorded about a 20% growth. Air conditioners sold in Australia are mainly imported from Southeast Asian countries. Led by Japanese manufacturers, the number of HFC-32 RAC units increased. The Australian government plans to put in place new MEPS for AC from April 2019 assessed by the Seasonal Energy Efficiency Ratio (SEER) for rating air conditioner energy efficiency. The current Energy Rating Label will be replaced with the Zoned Energy Rating Label.

Brazil: The Brazilian RAC market increased to 2.5 million units in 2017 with Chinese and South Korean manufacturers leading the market. RAC imports from China also increased, driven by OEM products from local producers. The major type is the wall-mounted single-split AC. Cooling-only is estimated to have a 60% share, and heat pump type a 40% share. Low-priced residential AC and packaged models are popular. On-line sales of AC account for 10% of total sales, but unlikely to expand further without an increase in independent installers. The Brazilian government enforced new MEPS for single-split air conditioners and packaged ACs during fiscal year 2018. According to the new MEPS for split, the threshold value will increase to an energy efficiency ratio (EER) 3.02.

China: the safety standard for refrigerating systems and heat pumps came into force on July 1, 2018. The standard eased the regulations on the use of flammable refrigerants. Both HFC-32 and HC-290 are allowed within their charging limits. The shift from HCFC-22 and R-410A to HC-290 and HFC-32 will accelerate and likely overtake R-410A by 2025.

Egypt: 523,000 AC units were sold in 2017. Local manufacturers dominate the market most of which meet lower levels of MEPS. Egyptian manufacturers participated in the EGYPRA project testing prototypes using low and medium GWP refrigerants. The final report is due to be released in 2019.

Europe Union: the market share of HFC-32 RACs is increasing in the context of the stricter F-gas Regulations. HC-290 units are also in the market and European countries are helping A5 countries adopt the technology through technical cooperation and by providing grants. One such example is GIZ in Germany which provided aid to Ghana to import 500 HC-290 units to encourage the use of this technology in the country.

India: AC production using HCFC-22 will be prohibited from January 2025, whereas (imports have been prohibited since July 2015.) A local manufacturer is producing HC-290 RACs. India was the first country to publish an integrated national cooling plan in March 2019: the India Cooling Action Plan, which is available at http://www.ozonecell.com/viewsection.jsp?lang=0&id=0,256,815

Japan, AC with HFC-32 which is widely adopted. For more information see Chapter 4.2.3.

Latin America: AC are mainly imported from Asian countries, mainly China. (individual markets are small for local investment in independent manufacturing. Many manufacturers purchase products from Chinese manufacturers on an original equipment manufacturing (OEM) basis. In countries like Panama and Columbia, air conditioner distributors, are selling products under their original brands, most of which are also OEM products from China. Chinese manufacturers are active in Argentina and other countries in Central and South America

Middle East, Saudi Arabia's ban on the import and manufacture of split-type air conditioners using HCFC-22 came into effect in January 2015. As an alternative, R-410A rotary compressors for tropical desert regions have been developed and have considerable sales. But most of these compressors were fixed speed to meet the MEPS requirements (JARN magazine)

New Zealand The room AC market remained mostly the same in last four years, while packaged ACs increased thanks to a stable construction market. Almost all RACs and packaged ACs are of an inverter type. For room ACs, R-410A models are popular. For packaged ACs, ceiling-concealed type R-410A units are the main sellers. The New Zealand government has developed the New Zealand Emissions Trading Scheme (NZ ETS) as its principal policy in response to climate change. Backed by this policy, R-410A refrigerant is being replaced by HFC-32. Japanese manufacturers dominate the market.

South Africa: the construction market is active. The room AC market in South Africa reached 167,000 units in 2017. For room ACs, heat pump type inverter are estimated at 75% of the market. For packaged units, the inverter rate increased to about 95%. Both split and packaged AC markets have already shifted from HCFC-22 to R-410A refrigerant.

Southeast Asia: Thailand, Indonesia, and Vietnam have a high percentage of HFC-32 room ACs, although HFC-32 units have yet to gain traction in the Philippines, Malaysia, Singapore, and other countries in the region.

United States, with strict regulations for flammable refrigerants, R-410A is a major refrigerant in the room AC segment. However, there is large workstream supported by various industry groups (AHRI and ASHRAE) which recognize the impending market shift towards more environmentally, energy efficient equipment. HFC-32 is SNAP[20] listed for AC units and is

[20] SNAP was established under Section 612 of the Clean Air Act to identify and evaluate substitutes for ozone-

being introduced by one major manufacturer. HFO-type blends are being introduced by various manufacturers and HC-290 and HC blend have been SNAP listed by one large commercial refrigeration manufacturer. Hydrofluoroolefin (HFO) refrigerant blends and HFC-32 are under development. HC-290 and 2 other HCs are SNAP listed for commercial refrigerators. For self-contained ACs, HC-290 is acceptable with use conditions.

depleting substances. The program looks at overall risks to human health and the environment of existing and new substitutes, publishes lists and promotes the use of acceptable substances, and provides the public with information.

Annex 2

Safety

Overview of RACHP safety standards

The requirements and implications of various international and regional safety standards covering RACHP sectors are detailed in report TEAP TF XXVIII/4.[21] This includes a table of relevant standards and the applicable various sub-sectors (Table 2-1). An extract of that table is provided below (Table I). Throughout the report there are discussions on what the upper charge limits are.

Table I: Scope of selected RACHP safety standards that include flammable refrigerants

Sector	Vertical (Product Standards)		Horizontal (Group Standards)
	IEC 60335-2-40	IEC 60335-2-89	ISO 5149-1,-2,-3,-4
Commercial refrigeration		×	×
Air-to-air air conditioners & heat pumps	×		×

Table II attempts to summarise the upper charge limits, where values have been separated into two categories.

- "with limited measures" means only with elimination of potential ignition sources
- "with additional measures" refers to situations where additional protective measures have to be applied, such as imposing a minimum room size, additional ventilation, etc.

It is not straight-forwards to summarise the "with additional measures" charge limits as they often depend upon the choice of several measures, installation conditions and so on. The exercise should be carried out on a case-by-case basis.

Table II: Maximum charge size limits for flammable refrigerants according to RACHP safety standards

	With limited measures			With additional measures		
	A3	A2	A2L	A3	A2	A2L
IEC 60335-2-89	0.15 kg	0.15 kg	0.15 kg	n/a	n/a	n/a
IEC 60335-2-40	0.15 kg	0.5 kg	1.8 kg	0.3 kg/1.0 kg	3.4 kg	8.0 kg/78 kg
ISO 5149	0.15 kg	0.5 kg	1.8 kg	1.5 kg/2.5 kg/ unlimited	3.4 kg/ unlimited	60 kg/ unlimited

All of these standards are in various stages of revision including with special attention to application of flammable refrigerants. Again, a summary of these maty be found in the TEAP TF XXVIII/4 report.

Overview of safe refrigerant handling

[21] TEAP TASK FORCE Decision XXVIII/4 Report: on safety standards relevant for low-GWP alternatives

In terms of refrigerant safe handling training, the situation differs widely amongst countries, due to the variety of national legislation. The IIR has published an information note on qualification and competence of technicians,[22] which offers an overview of schemes available in many countries.

Some international and regional standard touch on the topic. An international standard is under preparation, ISO 22712 - Refrigerating systems and heat pumps — Competence of personnel (currently in the form EN 13113), which addresses the required competence of technicians for all refrigerant types and tasks. More specifically, IEC 60335-2-40 includes an Annex (DD) covering requirements for operation, service and installation manuals of appliances using flammable refrigerants, which is essentially a compilation of procedures. Another annex (HH) addresses "Competence of service personnel". Whilst neither IEC 60335-2-89 nor ISO 5149 contains any such material, EN 378-4 does have a short annex on competence of persons working with flammables.

Most countries tend to operate training programmes that are either national or private schemes. There are also a number of regional training programmes in existence, such as the "Real Alternatives" scheme, which covers most of the European countries.[23] In North America there are two such schemes: North America Training Excellence (NATE) for HVAC[24] and AHAM-Home Appliance[25]. China operates a national training scheme for flammables as does JRAIA in Japan.

The entire topic is rather disparate, but it is expected that the global approach will become more harmonised as introduction of flammable refrigerants become more prevalent.

[22] http://www.iifiir.org/userfiles/file/publications/notes/NoteTech_28_EN.pdf

[23] https://www.realalternatives.eu/learning-platform

[24] https://www.natex.org/site/1/Homehttp://

[25] www.aham.org/AHAM/Safety/Safe_Servicing_of_Cold_Appliances/AHAM/Safety/Safe_Servicing_of_Cold_Appliances.aspx?hkey=23d1344d-f8b0-410a-9e21-8181048b2b82